AN INVESTIGATION OF THE USE OF LICHENS AND MOSSES AS BIOMONITORS OF ACIDIC PRECIPITATION IN ONTARIO

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Report prepared by:
CASE Biomanagement

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ABSTRACT

The levels of Al, As, Ca, Cd, Cl, Cr, Cu, Fe, K, Mg, Mn, N, Na, Ni, P, Pb, S, Ti, V, and Zn elements in the lichens *Cladina mitis* and *C. rangiferina*, and the moss *Pleurozium schreberi*, were determined in samples collected at 44 locations throughout Ontario. Levels of As, Hg, and Se were measured in a few selected samples. Concentrations were found to be quite variable from place to place. The spatial patterns of elemental concentrations suggest that they were partially related to acid precipitation chemistry and to local sources of air pollution such as urban environments and smelters.

A sample grinding experiment was conducted to compare the results obtained from sample replicates ground in preparation for analysis using a Wiley mill with those ground under liquid nitrogen. It was found that use of a Wiley mill sometimes resulted in elevated levels of metal in the lichens, presumably because of metal chips from the mill blades. Otherwise the results obtained by the two methods were comparable within the limits of the sensitivity of the analytical methods used to analyze them.

Samples of lichen and moss collected three times per year from the APIOS biogeochemistry study sites and analyzed to determine the levels of Al, As, Ca, Cd, Cl, Cr, Cu, Fe, K, Mg, Mn, N, Na, Ni, P, Pb, S, Ti, V, and Zn, revealed that the elemental contents of lichens at a site were not constant throughout the time period covered. There was insufficient data to say whether or not the fluctuations were seasonal

The lichen flora at Hawkeye Lake in NW Ontario is relatively undisturbed. At High Falls, near Sudbury, acidophilic species dominate an impoverished crypotogamic flora. Many of the epiphytic species, for example *Parmelia sulcata*, now occur only on trees with neutral to basic pH bark. At Plastic Lake, south of Dorset, the cryptogamic flora has started to show impact but the damage is not as severe as at High Falls. Many of the species at Plastic Lake were stunted, discoloured, and eroded.

Lichen quadrats were established and photographed on 120 trees at the APIOS biogeochemistry sites in order to document the lichens growing there. This was done to provide a benchmark for future comparisons. It was observed that trees at Hawkeye Lake had apparently normal epiphytic lichen populations. Epiphytic lichen populations at Plastic Lake were much simplified and consisted of only a few species, all of which exhibited discolouration. At High Falls, near Sudbury, the epiphytic lichen flora was reduced.

Well defined geographic concentration patterns were observed for Fe, Mg, K, N, Pb, and S in *Cladina*. Regional gradients of N, Pb and S concentrations were evident with the highest concentrations being found in central and north-central Ontario and the lowest in northern and northwestern Ontario. More localized accumulations existed for Fe, Mg, and K, but these were not as well defined. The regional distributions illustrated by the lichens agreed with other indirect measurements of sulphur deposition.

Sulphate, nitrate and lead in precipitation appear to be major contributing factors to the accumulation of S, N and Pb in *C. mitis*. Otherwise, the element content of precipitation does not appear to be the major factor influencing the accumulation of the bioactive elements in the lichens and mosses analyzed.

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"If you haven't measured it, it ain't science...it's opinion."
— Lazarus Long

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1. BACKGROUND

Acidic precipitation has become a topic of world wide interest. It is recognized that lichens are very sensitive to the effects of air pollution and we wondered if they could be used to study the distribution and relative impact of acidic precipitation throughout Ontario.

In 1982, Ontario Ministry of the Environment commissioned CASE Biomanagement to undertake an investigation of the relationship between acid precipitation and populations of lichens and mosses in Ontario. This report presents the analytical results of the investigation, and their interpretation with respect to precipitation chemistry. In addition, it presents a discussion of the relationships among the elemental contents in the lichens and mosses.

1.1. Terminology

1.1.1. Acidic Precipitation

The term 'acid rain' or 'acidic precipitation' can be misleading because it implicitly suggests that pH is the only, or at least the most important factor directly responsible for the environmental changes apparently related to precipitation that have been documented in Europe and North America over the last decade and a half. If the chemical composition of the precipitation is studied, however, it is apparent that it contains the same compounds as uncontaminated rain but in very different amounts and proportions. While acidic precipitation may be more acidic due to excess sulphuric and nitric acid concentrations, environmental impact due to 'acid rain' is actually a multivariate problem because of the presence and interactions of many bioactive elements and compounds.

The problems related to the deposition of acid precipitation are not due solely to changes in pH or the presence of sulphur and nitrogen compounds (Krause *et al.*, 1986). Research from around the world now implicates many factors, including increased mobility of metals released from minerals in the soil because of decreased soil pH (Andersson, 1986; Freiesleben and Rasmussen, 1986; Krause *et al.*, 1986). This enrichment is exacerbated by the deposition of particulates or precipitation containing metals and other bioactive elements (Krause *et al.*, 1986). Anthropogenic 'heavy' metals bound up in organic compounds in the soil are also potentially susceptible to leaching by acidic deposition (LaZerte, 1986).

1.1.2. Biomonitoring

Many instrumental studies have documented accumulation patterns of sulphur and bioactive elements in the vicinity of industrial facilities and regions of acid precipitation. Until recently, very little visible damage to moss and lichen or vascular plant communities in forest ecosystems in North America had been related to the deposition of 'acid rain', except in areas of high levels of SO_2 emissions, such as the Sudbury and Wawa areas. It now appears that the apparent lack of symptoms may not be an actual lack of impact; rather, the degree of environmental perturbation was not initially sufficient to manifest itself as gross damage to the more conspicuous ecosystem components. Recent evidence from European studies suggest that forest die-back or decline is related to many factors, including $SO_2/O_3/NO_x$ emissions, changes in soil chemistry, and long term exposure to acidic precipitation enriched with bioactive elements and compounds (Fabiszewski, 1987; Gärtner, 1987; Horst, 1987; Küppers and Blind, 1987; Mansfield, 1987; Meyberg *et al.*, 1987; Legge and Crowther, 1987).

It was during the period of this study that 'Maple die-back' came to be recognized as a problem in Canada (McLaughlin *et al.*, 1985), in areas where ground-dwelling (terricolous) lichens exhibited elevated levels of bioactive elements. Thus lichens and mosses, especially epiphytic species, are not only sensitive biomonitors but they can apparently survive and accumulate

contaminants in areas where long-term exposure to the same contaminants is starting to manifest itself on vascular species.

Tree-dwelling epiphytic lichens obtain the greatest proportion of their elemental constituents from air borne particulate matter or dissolved in water as precipitation (Larson, 1987). For this reason, lichens provide a good indication of the 'average' elemental contribution by dry and wet atmospheric deposition. It is quite open to question whether lichens derive any nutriment from the support (substrate) at all (Brodo, 1973). However, inorganic minerals and organic substances found in, or washed from, the substrate surfaces seem to be of great significance in lichen distribution (Brodo, 1973). Lichens are able to take up organic substances and inorganic minerals from stem flow and they are frequently concentrated in the vicinity of stem flow tracks (Barkman, 1958).

Ground dwelling lichens obtain a portion of their elemental constituents from water in the soil, and their composition provides a reliable index of the levels of bioactive elements leached from soil minerals. For these reasons, lichens (and mosses) provide a means of easily and rapidly surveying large regions to locate 'hot spots' of bioactive element availability.

The influence of airborne pollutants is complex and the organisms most at risk are those which are further up the food chain since many toxic materials accumulate along food-webs. Some of the first organisms to show changes in their elemental composition are lichens and mosses because of their ability to accumulate pollutants and pollutant by-products toxic to other organisms. At the same time they are very sensitive to the toxic effects of SO_2. By selecting a sensitive group of species such as lichens and mosses as biomonitors it is possible to detect the bioaccumulation of metals or other trace elements, and to investigate any possible effects before extensive injury to higher plants results.

Field studies have shown that, in general, lichens and mosses are more susceptible to damage from exposure to phytotoxicants such as SO_2 than are vascular plants (Ferry *et al.*, 1973). This sensitivity does not appear to be due to any inherent physiological difference but rather to the inability of lichens or mosses to 'avoid' pollutant uptake. It has also been shown that higher plants can suffer major biochemical or physiological alterations related to the ability of roots to take up nutrients in areas where lichens and mosses have been visibly damaged but not totally eradicated. The rationale behind using lichens and mosses as biomonitors of phytotoxic air pollutants is based on the assumption that, if the mosses and lichens in an area are not damaged or have not accumulated significant amounts of contaminants, then the less sensitive higher organisms present should also be unaffected.

Work by Case (Case, 1980; Case *et al.*, 1985) and many others (Ferry *et al.*, 1973; Addison and Puckett, 1980; Nygård and Harju, 1983; to mention only a few) has demonstrated the value of lichens and mosses as early warning biomonitors of trace element deposition. The most reliable measures of lichen conditions are community structure, percentage cover, number of species per unit area, elemental analyses of tissue, and membrane leakage. Lichens and mosses near a pollution source accumulate high concentrations of emitted elements by absorptive and adsorptive processes as well as by incorporation of particulate matter into their tissues. The status of these plants can, in turn, be related to impacts on other ecosystem components. The level and rate of accumulation are related to distance from the source and prevailing wind conditions as well as the specific element or compound and its ionic form, exposure, habitat and plant morphology. Mapping lichen and moss elemental contents provides a reliable, inexpensive, and practical method for detecting the presence of trace contaminants (surveillance) and mapping their deposition (monitoring). It is also more sensitive and provides results which are easier to interpret than data from surveys of vascular plant elemental contents.

1.1.3. 'Bioactive' Element Content of Plant Tissue Samples

The term 'heavy metal' is not a particularly good one because it has been used by different people to refer to different groups of elements which are usually associated with pollution, but

which often include many non-metallic elements. There has been a movement to replace the term 'heavy metal' with a more biologically and chemically meaningful one, based on the atomic properties of the elements and the element ion/ligand complexes (Nieboer and Richardson, 1980). The term 'bioactive element' is used in this report instead of 'heavy metal' to refer to elements measured in precipitation which have potentially important biochemical and biological implications for ecosystems.

1.2. Reasons for Biomonitoring

Biomonitoring provides information about the actual responses of organisms to pollutants. In contrast, physical measurements, however precise or expensive, still have to be interpreted within the context of factors operating within the ecosystems which are so complex that not all the variables have yet been identified. Biomonitoring site locations can be located independently of power sources during the exposure period which allows much greater flexibility in the placement and number of sampling sites. This makes them less expensive to establish and maintain than instrumented stations. They are also inconspicuous and unlikely to be vandalized.

Biomonitoring may be employed to see if there are elevated concentrations of potentially toxic contaminants in the environment and whether there are any trends in these levels. The quantitative data resulting from such surveys may be part of a contaminant budget assessment from source (emission) through transmission (dispersion and transformation) to sinks (immission). In turn, these data could be linked to studies of the quality of human, animals and plant health, used to plan the location of instrumented air quality monitoring stations and to elucidate possible cause and effect relationships.

Biomonitoring may be undertaken to assess the needs for emission control around industrial sources of pollution. Monitoring may also be employed in relation to multiple sources to provide some understanding of pollutant distribution or to facilitate the development of dispersion models. Data from biomonitoring surveys can be used to map the location of pollution sources, or document contaminant deposition. More and more, biomonitoring is being undertaken to provide a historical record of environment quality and ecosystem composition in relation to recommended objectives or standards, and as a basis for environmental impact assessment.

For example, the author conducted a study of more than 30,000 individual elemental concentration measurements for more than 600 samples collected at 120 sites in the vicinity of the world's largest open pit mine near Fort McMurray, Alberta, and was able to map the deposition of trace elements throughout a region with a 100 km radius (Case *et al.*, 1985; Dabbs, 1985). In an earlier Norwegian study (Hanssen *et al.*, 1980), samples of *Hylocomium splendens* from 510 localities were analysed for a large suite of elements which could be related to acid precipitation deposition. The trace element concentrations in lichen and moss samples can be calibrated with instrumental data and used as a quantitative measure of the deposition of trace elements. Based on the analysis of annual mean volume weighted precipitation chemistry (Table 1), comparisons can be made between estimated annual net deposition and the element concentration in lichen and moss samples around the precipitation sampling sites. The concentration patterns can be used to map patterns and assess the relative contribution to contaminant deposition due to long range transport and local point sources.

Table 1. Depth weighted precipitation chemistry at APIOS monthly cumulative sampling stations, 1981.*
Source: Kirk, 1983. ARB-102-83-ARSP APIOS-008/83

Station	Al mg/L	Cd mg/L	Ca mg/L	Cl mg/L	Cu mg/L	Fe mg/L	Pb mg/L	Mg mg/L	Mn mg/L	Ni mg/L	P mg/L	K mg/L	Na mg/L	SO4 mg/L	Zn mg/L
Alvinston	0.062	0.00024	0.468	0.168	0.0041	0.0812	0.0075	0.089	0.0058	0.0008	0.0200	0.070	0.061	3.96	0.020
Attawapiskat	0.026	0.00016	0.471	0.125	0.0089	0.0386	0.0044	0.082	0.0028	0.0014	0.0068	0.052	0.056	1.35	0.008
Bear Island	0.150	0.00022	0.232	0.109	0.0034	0.1537	0.0056	0.044	0.0064	0.0011	0.0429	0.062	0.050	3.01	0.015
Campbellford	0.058	0.00023	0.348	0.207	0.0054	0.0620	0.0078	0.048	0.0037	0.0006	0.0269	0.055	0.092	3.53	0.010
Colchester	0.059	0.00020	0.470	0.258	0.0048	0.0751	0.0098	0.110	0.0049	0.0005	0.0216	0.068	0.091	5.40	0.014
Coldwater	0.019	0.00022	0.183	0.079	0.0021	0.0346	0.0064	0.015	0.0016	0.0006	0.0128	0.037	0.033	2.26	0.008
Dalhousie Mills	0.044	0.00028	0.341	0.198	0.0050	0.0660	0.0074	0.042	0.0038	0.0006	0.0372	0.058	0.104	3.31	0.010
Dorion	0.047	0.00013	0.184	0.064	0.0052	0.0555	0.0042	0.026	0.0019	0.0005	0.0240	0.035	0.045	1.69	0.009
Dorset	0.050	0.00016	0.249	0.135	0.0018	0.0714	0.0064	0.040	0.0041	0.0007	0.0132	0.040	0.049	3.64	0.007
Ear Falls	0.041	0.00013	0.144	0.122	0.0066	0.0470	0.0064	0.063	0.0153	0.0033	0.0502	0.069	0.053	1.20	0.009
Exp. Lakes Area	0.021	0.00015	0.195	0.020	0.0063	0.0456	0.0052	0.024	0.0029	0.0005	0.0146	0.020	0.025	1.84	0.009
Golden Lake	0.018	0.00023	0.260	0.184	0.0034	0.0289	0.0076	0.049	0.0035	0.0005	0.0377	0.095	0.075	3.53	0.009
Gowganda	0.057	0.00033	0.199	0.092	0.0031	0.0741	0.0062	0.033	0.0047	0.0008	0.0751	0.103	0.053	3.25	0.012
Huron Park															
Kaladar	0.029	0.00010	0.278	0.221	0.0040	0.0380	0.0084	0.042	0.0028	0.0006	0.0283	0.072	0.129	3.63	0.007
Killarney	0.085	0.00019	0.276	0.104	0.0040	0.0328	0.0069	0.047	0.0049	0.0013	0.0143	0.046	0.043	3.67	0.013
Mattawa	0.094	0.00023	0.225	0.148	0.0027	0.1016	0.0062	0.038	0.0049	0.0016	0.0135	0.070	0.069	3.14	0.007
McKellar	0.057	0.00020	0.306	0.191	0.0049	0.0735	0.0054	0.060	0.0046	0.0009	0.0156	0.084	0.091	3.17	0.011
Merlin	0.059	0.00018	0.495	0.240	0.0038	0.0689	0.0079	0.114	0.0038	0.0013	0.0213	0.066	0.091	4.74	0.008
Milton	0.045	0.00033	0.520	0.315	0.0033	0.0770	0.0144	0.116	0.0057	0.0007	0.0283	0.057	0.175	4.73	0.014
Moonbeam	0.018	0.00026	0.171	0.092	0.0034	0.0229	0.0031	0.050	0.0025	0.0006	0.0395	0.085	0.043	1.84	0.011
Nakina	0.058	0.00010	0.458	0.120	0.0053	0.1148	0.0039	0.090	0.0075	0.0005	0.0266	0.064	0.042	1.78	0.010
Palmerston	0.050	0.00025	0.409	0.201	0.0052	0.0645	0.0079	0.111	0.0048	0.0011	0.0188	0.062	0.104	4.39	0.016
Pickle Lake	0.064	0.00016	0.331	0.128	0.0072	0.0632	0.0028	0.063	0.0063	0.0005	0.0317	0.075	0.055	1.13	0.006
Port Stanley	0.061	0.00027	0.362	0.195	0.0039	0.0519	0.0082	0.090	0.0050	0.0006	0.0202	0.045	0.063	4.69	0.011
Quetico Centre															
Ramsey	0.076	0.00010	0.214	0.076	0.0035	0.0692	0.0045	0.033	0.0045	0.0008	0.0163	0.051	0.045	2.25	0.010
Shallow Lake	0.034	0.00027	0.247	0.139	0.0039	0.0468	0.0075	0.051	0.0029	0.0007	0.0189	0.037	0.058	3.46	0.010
Smith's Falls	0.045	0.00012	0.587	0.178	0.0045	0.0537	0.0078	0.127	0.0052	0.0008	0.0386	0.056	0.094	3.43	0.009
Uxbridge	0.048	0.00023	0.504	0.226	0.0048	0.0614	0.0082	0.072	0.0046	0.0006	0.0200	0.041	0.067	4.29	0.009
Waterloo	0.062	0.00031	0.558	0.229	0.0055	0.0812	0.0091	0.154	0.0065	0.0008	0.0324	0.100	0.094	3.82	0.013
Whitney	0.041	0.00016	0.145	0.100	0.0046	0.0633	0.0052	0.020	0.0025	0.0007	0.0207	0.057	0.035	2.85	0.008
Wilberforce	0.027	0.00187	0.205	0.136	0.0051	0.0547	0.0108	0.030	0.0039	0.0011	0.0156	0.126	0.053	3.67	0.009
Wilkesport	0.058	0.00031	0.602	0.275	0.0043	0.0670	0.0101	0.095	0.0058	0.0006	0.0382	0.066	0.077	5.25	0.012

* For most stations, period of record is from Dec 31/80 to Jan 5/82.

1.3. Advantages of Mosses and Lichens as Biological Monitors

Lichens and mosses were selected as the biomonitors for this study because they have been shown to be excellent and nearly continuous collectors of airborne bioactive elements (including radionuclides), sulphurous compounds, and some hydrocarbons. In addition, air dried samples of lichens and mosses can be archived and chemically analyzed even years later, to provide quantitative information about levels of elements in the environment at the time of sample collection. Lichen and moss physiology and ecology are sufficiently well understood that conclusions can be drawn about the pollution conditions from observations of the condition and chemical content of the organisms.

Lichens and mosses are naturally occurring species which grow on substrata that do not greatly buffer them from the effects of pollutants and that persist after the death of the species. They also respond quickly to increased pollution emissions, and the species vary in their relative pollution tolerance. Except in disturbed areas, lichens and mosses are generally available in sufficient quantity that unbiased sampling is possible.

1.4. Other Roles of Lichens and Mosses

Quite apart from their value in assessing air quality, lichens and mosses are important components of many ecosystems. In addition to their traditional role as 'pioneers' in soil formation, soil retention, and colonization of disturbed habitats, they are important in nitrogen fixation, evaporation, and nutrient cycling. The relationships of these nutrient cycles to lichen utilization by caribou, reindeer, lemmings, birds and many invertebrates, has been documented in Europe and North America (Crittenden and Kershaw, 1978).

The extensive moss-lichen mats in Canada's forested regions play an important part in the control of regional water balances through their mulching effect on the soil surface (Rouse, 1976). By ameliorating soil surface temperatures and reducing evaporative stress, this mat influences establishment and survival of vascular plant seedlings and is an important factor in natural forest regeneration (Kershaw, 1977).

1.5. Objectives of this Study

These lichen and moss studies had a dual purpose:

- to develop a model relating levels of selected chemical parameters in lichens and mosses to related parameters in precipitation in Ontario and to assess the model as a method of mapping acidic deposition across the province.

- to develop a method to monitor changes in lichen and moss populations that could be related to acidic deposition or other long-range transport pollutants in Ontario.

2. PHOTOMETRIC BENCHMARK

2.1. Introduction

The vitality or health of lichens is reflected in their visual appearance. If lichens are exposed to toxic levels of airborne contaminants they will, overtime, develop visible symptoms of injury including changes in colour, deformation of the thallus, stunted growth, necrosis and changes in reproductive status. Associated with the development of such symptoms there is a decrease in the production of new tissue and in many instances, eventual disassociation of the thallus and its subsequent disappearance. A photometric benchmark was conducted at the BGC sites with photographic documentation of the lichen cover in permanent quadrats. The BGC sites are watersheds under intense investigation by the Ministry of the Environment, with respect to bio-geochemical cycling pathways and transformation processes.

2.2. Purpose

The purpose of this project was to photographically document the condition of lichens in permanent uniform quadrats, using procedures that would not only allow identification of the species present but also accurate measurement of the lichen thalli areas. This would provide a benchmark database for comparison with possible future studies. Only if such a database existed would it be possible to measure any changes in lichen size, cover, and floristic composition sometime in the future. The method employed also provides the lichenologist with a photographic record of lichen vitality and visual symptoms of injury.

2.3. Methods

2.3.1. Site Selection and Description

A series of permanent lichen quadrats were established on trees at each of the BGC study sites. All trees used were free of visible signs of disease or injury, and were not leaning more than about 5°. The trees were at least 100 m from gravel roads, at least 50 m from paved roads, and at least 50 m from the edge of the forest canopy. The lichen selected for use was *Parmelia sulcata*.

2.3.2. Equipment

The photographic sampling technique employed in the APIOS lichen and moss study utilized a photographic apparatus developed over a 5 year period by the author and Mr. D.L. Dabbs, of Dabbs Environmental Services. Uniformity of film exposure and magnification was maintained by using a shadow box apparatus and microprocessor controlled flash as a light source. A camera was mounted in one end of the box and the quadrat was photographed through a hole in the other end of the box.

Hand-holding a camera introduces serious error in the determination of the size of the lichen because the film plane is not necessarily parallel to the subject plane. This can introduce significant parallax distortion of the recorded images that can amount to one or more orders of magnitude greater than the growth of the lichens over a several year period.

The apparatus locked the camera to a rigid frame in exactly the same position for every photograph. This was achieved by means of a clamp mount around the lens, set at the correct focal length for the depth of the shadow box. Camera bodies could be easily exchanged in the field to take backup pictures without having to remove the lens from the shadow box frame. An electronic flash controlled by a microprocessor in the camera provided exactly the same amount of light for each photograph. This was calibrated using a uniform grey background.

A SLR camera and 50 mm lens were used to photograph each quadrat. The corners of each 10 x 20 cm quadrat were marked with aluminum nails. The boundaries of the quadrat were

temporarily outlined during the photography using an elastic white string loop stretched around the corner nails. This allowed the scale to be correctly determined for each photograph, since the distance between the upper and lower borders was known it would not change significantly due to tree growth between resurveys. The method of analysis precisely corrects for any variance in scale.

Kodachrome film (ASA 25) was used. All film was of the same emulsion number. The film was sent to the processing lab by bonded-courier.

2.3.3. Quadrat Placement

Twenty (20) permanent 10 x 20 cm quadrats were established vertically on the dominant 2 or 3 tree species at each of the BGC study sites. Quadrats were established on the trees over *P. sulcata* thalli so that they were as nearly as possible centred at 1.3 m above the ground on the north-facing (0° true north) side of the tree. Quadrat placement was standardized to eliminate as much variability as possible. The exact placement was marked by aluminum corner nails, as noted above.

Each tree was marked with an aluminum numbered identification tag attached to the tree with aluminum nails directly below the quadrat so that the tag would appear in the photograph. The distance and direction of each tree from the preceding one, or some identifiable landmark, was recorded. The slides are on deposit in the offices of Ministry of the Environment, Toronto, Ontario.

2.3.4. Lichen Thallus Measurement

Cover by *P. sulcata* thalli in the quadrats was measured using a computerized planimetry system consisting of a Bausch & Lomb HIPAD digitizing tablet interfaced to an Apple™ /// microcomputer. A darkroom enlarger was used to project a photo image of the quadrat onto the digitizing tablet to prevent distortion. (Alternately, enlargement prints from the slide could be placed directly on the tablet.) The outline of each lichen thallus was traced on the tablet and its area calculated by the microcomputer. By measuring each thallus separately, the loss of information due to sloughing of lichen-bearing bark scales in the future is minimized.

2.3.5. Database Management

Each thallus traced was assigned a unique identification number and a record was maintained of the site, quadrat, tree species, year, lichen species and size measurement. Data were archived in a microcomputer based database. Data could be stored, sorted, retrieved, and reported in any required format according to site, species, element, year or any combination thereof. In addition, as plain text (ASCII) files, they could be made available to other micro-, mini- and Mainframe computers.

2.4. Results

Cover by *Parmelia sulcata* in the permanent quadrats established at the BGC sites provides a benchmark for future comparison but does not represent a 'time zero' situation. The thallus measurements of *P. sulcata* in the quadrats are presented in Appendix B of this report. All files have been archived pending future photometric surveys.

2.5. Discussion

The average lichen thallus of *P. sulcata* in quadrats photographed at Hawkeye Lake had an area of 206 mm^2 with some thalli as large as 4300 mm^2. At Plastic Lake the average size of the *P. sulcata* thalli was only 82 mm^2 and the largest thallus was only 2445 mm^2. At High Falls, the average size of the *P. sulcata* thalli was still smaller at only 47 mm^2 and they were restricted to *Populus* tree species which have neutral to basic bark pH. The largest *P. sulcata* thallus photographed at High Falls was only 867 mm^2.

The epiphytic lichen thalli photographed in standardized quadrats at the BGC sites showed marked differences in the health at each site. Visual examination of the photographs revealed that the lichens at Hawkeye Lake were typically very healthy, had normal coloration and in some instances were large and luxuriant. At Plastic Lake the thalli never reached the size of those found at Hawkeye Lake. In addition, they were frequently discoloured, taking on a darker grey cast and sometimes had bleached or necrotic spots. The *P. sulcata* thalli at High Falls were absent from the coniferous trees and were restricted to the trunks of *Populus tremuloides*, a tree species noted for its neutral to basic bark pH. The largest *P. sulcata* thalli found at High Falls were much smaller than those at Plastic Lake and Hawkeye Lake.

The green lichen *Bacidia sabuletorum* was frequently the dominant lichen in quadrats on coniferous trees at Plastic Lake. This species is known to be more tolerant of air pollution and eutrophied environments than other species such as *P. sulcata*. Only traces of this species were found on coniferous trees at Hawkeye Lake and it was not found on coniferous trees at High Falls.

2.6. Conclusions

The photographs of the lichen quadrats have captured information about the relative health of the lichens at the BGC study sites. It is apparent that lichens at Hawkeye Lake are larger, healthier and more luxuriant than at the other sites. It is concluded that Hawkeye Lake had the most pristine environment.

At Plastic Lake the epiphytic lichens were generally smaller, appeared to be less vigorous and was made up largely of pollution tolerant species. It is concluded that the preponderance of *Bacidia sabuletorum* on trees at Plastic Lake is indicative of a eutrophied environment.

The greatest impact was apparent at High Falls. There, lichens were almost totally absent from trees with acidic bark. Lichens normally found on acidic substrata were found growing on the bark of *Populus tremuloides* trees which have neutral to basic bark pH. It is concluded that the bark of the *P. tremuloides* was able to neutralize what ever acidifying factor(s) are making the bark of coniferous trees an unsuitable substrate for lichen growth.

Comparison of future photometric survey results with the benchmark database will permit monitoring of lichen thallus size to see if conditions are changing at the BGC study sites.

3. A COMPARISON OF GRINDING METHODS

3.1. Introduction

An experiment was conducted to compare analysis results obtained from sample replicates ground in a Wiley mill with those ground under liquid nitrogen.

3.2. Purpose

The purpose of the grinding method comparison was to determine if these two methods of sample preparation would result in significant differences in the elemental analysis results.

3.3. Methods

A separate set of samples was collected during the lichen and moss survey for use in the comparison of grinding methods. One set of sample replicates were ground with a Wiley mill and another set were ground under liquid nitrogen in a chilled mortar and pestle. The mill was cleaned between each sample and plastic gloves were worn at all times when handling the samples. The sample jars were clearly labeled with a unique sample number on both the jar and the lid. Samples were submitted to the Ontario Ministry of the Environment laboratory in Toronto for concentration measurements.

3.4. Results

The results of the grinding method comparison are presented in Table 2. These results are for a separate subset of samples used only for the grinding experiment and were not part of the Province wide survey of lichen and moss elemental content. The data in Table 2 are not included in Appendix A. In both *Cladina rangiferina* and *Pleurozium schreberi*, the variation in elemental content between replicates was quite high, as indicated by the standard error values. There was considerable variation in elemental content, not only between between replicates of the same species, but also between different species. The methods employed to determine Cd, Cl, Mo and S content were apparently not sufficiently sensitive to reveal the variation of these elements. The average Ni content of *C. mitis* and *P. schreberi* was higher in samples ground with a Wiley mill than in sample replicates ground in liquid nitrogen with mortar and pestle. For all other elements, there was no significant difference between the methods (Table 3).

3.5. Discussion of Grinding Method Comparison

Student's *t*-test and the *F*-test were used to test the null hypothesis that there was no difference between the average elemental content measured in replicates ground in a Wiley mill and those ground under liquid nitrogen (Ho: $\mu1 - \mu2 = 0$), against the alternate hypothesis that the grinding method used made a difference (Ha: $\mu1 \neq \mu2$) (Table 3).

The observed t and F values indicate that for most elements, the choice of grinding method had no significant effect on elemental measurements obtained. However, in the case of Ni, there were significant differences found for *Cladina rangiferina*. When the corresponding t and F values are examined for *Pleurozium schreberi* it is noted that the differences in Ni values obtained using the different grinding methods is nearly significant. The Na values obtained for *P. schreberi* were significantly affected by the grinding method used.

3.6. Conclusions

The results of the grinding comparison conducted in this study seem to belie many of the concerns regarding the appropriateness of grinding the cryptogamic vegetation samples with Wiley mills using stainless steel blades, given the precision analytical methods used for elemental analysis. It was found, however, that the Ni contents of *Cladina rangiferina* samples were affected by grinding method. This is interpreted as being the result of Ni containing stainless steel shavings being introduced into the sample.

Table 2. Concentrations of elements in *Cladina rangiferina* and *Pleurozium schreberi* collected at Dorion, Ontario

Species	Method	Al ppm	Ca ppm	Cd ppm	Cl %	Cu ppm	Fe ppm	K ppm	Mg ppm	Mn ppm	Mo ppm	N mg/g	Na ppm	Ni ppm	P mg/g	Pb ppm	S %	Zn ppm
Cladina	Liq. N	1590	607	0.3	0.01	1	1200	0.19	967	24	0.5	5.6	270	1	0.4	10	0.02	19
Cladina	Liq. N	2030	964	0.2	0.01	1	1520	0.23	1300	43	0.5	5.6	143	1	0.4	13	0.04	23
Cladina	Liq.N	1200	1960	0.5	0.01	2	988	0.32	1030	71	0.5	7.2	220	1	1.0	8	0.04	25
Cladina	Liq.N	2340	1280	0.2	0.01	1	1810	0.29	1620	46	0.5	6.2	205	2	0.5	12	0.03	22
Cladina	Liq.N	1590	1100	0.2	0.01	1	1510	0.24	1120	40	0.5	5.5	243	1	0.5	17	0.02	22
Cladina	Liq.N	1600	602	0.4	0.01	1	1500	0.2	910	26	0.5	8.2	130	1	0.6	13	0.03	22
Cladina	Liq.N	1820	942	0.2	0.01	2	1370	0.24	1300	42	0.5	6.6	185	1	0.6	10	0.02	21
	Average	1739	1065	0.3	0.01	1	1111	0.24	1178	42	0.5	6.4	199	1	0.6	12	0.03	22
	Std Dev	367	465	0.1	0.00	0	263	0.05	247	15	0	1	51	0	0.2	3	0.01	2
	SE	139	176	0	0.00	0	99	0.02	93	6	0	0.4	19	0	0.1	1	0.00	1
Cladina	Wiley	1720	1270	0.2	0.01	1	1310	0.26	1220	49	0.5	5.6	185	3	0.5	13	0.03	20
Cladina	Wiley	1760	616	0.5	0.01	2	1640	0.25	1140	28	0.5	9	98	2	0.6	14	0.04	23
Cladina	Wiley	2270	983	0.2	0.01	1	2090	0.25	1470	37	0.5	5.9	168	5	0.5	19	0.04	22
	Average	1917	956	0.3	0.01	1	1680	0.25	1277	38	0.5	6.8	150	3	0.5	15	0.04	22
	Std Dev	307	328	0.2	0.00	1	392	0.1	172	11	0.0	1.9	46	2	0.1	3	0.01	2
	SE	177	189	0.1	0.00	0	226	0.00	99	6	0	1.1	27	1	0	2	0.00	1
Pleurozium	Liq.N	1650	4890	0.2	0.01	5	1390	0.53	1410	335	0.5	9.6	215	3	1.4	15	0.08	39
Pleurozium	Liq.N	1270	9140	0.7	0.03	9	1000	0.79	1540	373	0.5	17.4	220	2	1.9	21	0.14	98
Pleurozium	Liq.N	2570	12100	0.5	0.01	6	2160	0.48	1820	778	0.5	18.1	220	3	1.9	30	0.16	101
	Average	1830	8710	0.5	0.02	7	1517	0.6	1590	495	0.5	15	218	3	1.7	22	0.13	79
	Std Dev	668	3624	0.3	0.01	2	590	0.17	210	246	0.0	4.7	3	1	0.3	8	0.04	35
	SE	386	2092	0.1	0.01	1	311	0.10	121	142	0.0	2.7	2	0	0.2	4	0.02	20
Pleurozium	Wiley	1250	8210	0.8	0.03	8	1280	0.82	1490	311	0.5	15.2	200	6	1.8	19	0.15	92
Pleurozium	Wiley	2190	10600	0.5	0.02	6	1870	0.57	1650	681	1.0	18.0	200	4	1.9	27	0.18	91
Pleurozium	Wiley	1420	5110	0.4	0.01	4	1360	0.69	1310	278	0.5	9.7	175	9	1.4	17	0.09	44
	Average	1620	7973	0.6	0.02	6	1503	0.69	1483	523	0.7	14.3	192	6	1.7	21	0.14	76
	Std Dev	501	2753	0.2	0.01	2	320	0.13	170	224	0.3	4.2	14	3	0.3	5	0.05	27
	SE	289	1589	0.1	0.01	1	185	0.07	98	129	0.2	2.4	8	1	0.2	3	0.03	16

Table 3. *t*-test and *F*-test values obtained from a comparison of elemental contents measured in moss (***Pleurozium schreberi***) and lichen (***Cladina rangiferina***) ground in a Wiley mill or under liquid nitrogen with a mortar and pestle.

	Pleurozium schreberi		*Cladina rangiferina*	
	t-test †	*F*-test††	*t*-test ‡	*F*-test‡‡
Al	-0.435	0.190	0.732	0.536
Ca	-0.280	0.079	-0.362	0.131
Cd	0.530	0.281	0.152	0.023
Cl	0.378	0.143	•	•
Cu	-0.400	0.160	0.135	0.018
Fe	-0.340	0.001	1.284	1.650
K	0.777	0.603	0.325	0.105
Mg	-0.685	0.469	0.619	0.383
Mn	-0.375	0.141	-0.373	0.139
Mo	1.000	1.000	•	•
N	-0.201	0.040	0.474	0.225
Na	-3.138	9.846	-1.43	2.045
Ni	2.46	6.05	3.820	14.593
P	-0.147	0.022	-0.306	0.093
Pb	-0.188	0.035	1.685	2.838
S	0.373	0.139	1.412	1.993
Zn	-0.143	0.020	-0.275	0.076

† a = 0.05, two-tailed, DF = 4, critical value = 3.182

†† $\mu_1 = 1, \mu_2 = 4$, a = 0.05, $F_{0.05} = 7.71$

‡ a = 0.05, two-tailed, DF = 4, critical value = 2.365

‡‡ $\mu_1 = 1, \mu_2 = 8$, a = 0.05, $F_{0.05} = 5.32$

4. SURVEY OF LICHEN AND MOSS ELEMENTAL CONTENT

4.1. Introduction

Samples of at least one of the lichens *Cladina mitis* and *C. rangiferina*, or the moss *Pleurozium schreberi*, were collected at 41 out of 44 sampling locations in Ontario. They were chemically analysed to measure the levels of selected elements. Geographical patterns of elemental accumulation in *Cladina mitis* in Ontario were generated. The data were analysed to determine if any relationship exists between chemical parameters in the samples, and the same parameters in precipitation. At 3 sampling locations, Attawapiskat, Lively/Walden and Winisk, these species were not sampled; other species were collected instead. These cases are indicated as *special* collections in Appendix A, which presents the results of the elemental analyses.

4.2. Purpose

Samples of lichens and mosses were to be collected from designated sites in Ontario, identified, and processed in preparation for chemical analysis. The species, number of samples and sampling locations were determined in consultation with Ministerial staff. These sites included, but were not necessarily restricted to, the APIOS (Acid Precipitation in Ontario Study) cumulative and event precipitation sampling sites. All samples were submitted to a Liaison Officer of the Ministry who in turn submitted them to the Ministry's Toronto laboratory for chemical analysis. Results of the chemical analyses were forwarded to the author in due course.

Based on the results of the analyses of replicates collected, an attempt was to be made to determine if any relationship might exist between selected chemical parameters in lichen and moss samples, and related precipitation chemistry parameters at designated sites throughout Ontario. The parameters to be used for the model and deposition maps derived from it were determined by the Ministry Liaison Officer in consultation with the author.

4.3. Baseline Bioaccumulation Sampling Methods

These methods are included in the OME field sampling procedures manual (OME, 1985).

4.3.1. Site Selection and Description

Samples of epiphytic and ground dwelling lichens and moss were collected at forty-three sampling sites established across Ontario (Figure 1) for the collection of lichen and moss samples. These sites were located as closely as possible to APIOS event and cumulative precipitation monitoring stations in order to facilitate comparison of precipitation chemistry with lichen and moss elemental composition.

Each sample site was established in a forested area which, as far a possible, lacked any sign of human disturbance, preferably on publicly-owned land. As much as possible, they were located away from local sources of atmospheric contaminants. Sampling areas were at least 100 m from gravel roads, at least 50 m from paved roads, and at least 50 m from the edge of the forest canopy.

To facilitate site relocation, coordinates were recorded in tabular form (Table 4). Site locations were also marked on air photos by means of pin holes through the photographs. The air photos are on deposit at the offices of the Ontario Ministry of the Environment, Air Resources Branch, Phytotoxicology Section, 880 Bay Street, Toronto, Ontario.

Figure 1. Sampling sites in Ontario.

Table 4. Sample collection site information.

1. Abitibi Canyon, Cochrane District. Habitat: coniferous woods. Elev. 230 m ASL. Latitude: 49° 53'N, Longitude: 81° 34'W.
2. Algonquin Park Boundary, 5 km N on Hwy 630. Habitat: Jack Pine woods on sand. Elev. 198 m ASL. Latitude: 46° 10'N, Longitude: 78° 55'W.
3. Attawapiskat, East shore of James Bay. Habitat: tundra. Elev. 3 m ASL. Latitude: 52° 56'N, Longitude: 82° 24'W.
4. Bear Island, Lake Tamagami. Habitat: Mixed woods. Elev. 305 m ASL. Latitude: 46° 58'N, Longitude: 80° 01'W.
5. Bond Tract, Agreement forest near Galt. Habitat: coniferous woods. Elev. 300 m ASL. Latitude: 43° 25'N, Longitude: 80° 20'W.
6. Bonnechere Caves, Round L. 20 km SW of Pembrook. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 45° 30'N, Longitude: 77° 05'W.
7. Capreol, 15 km N of Sudbury. Habitat: coniferous woods. Elev. 300 m ASL. Latitude: 46° 48'N, Longitude: 80° 52'W.
8. Clarendon, Hwy 509, 10 km N of Hwy 7. Habitat: mixed woods. Elev. 200 m ASL. Latitude: 44° 55'N, Longitude: 76° 40'W.
9. Dalhousie Mills, SE Ontario. Habitat: Sumac grasslands. Elev. 69 m ASL. Latitude: 45° 25'N, Longitude: 74° 30'W.
10. Dorion, NW Ontario. Habitat: Boreal forest. Elev. 244 m ASL. Latitude: 48° 48'N, Longitude: 88° 33'W.
11. Dummer, 6 km N Hwy 7, 3 km E Norwood. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 44° 25'N, Longitude: 77° 58'W.
12. Ear Falls, NW Ontario. Habitat: boreal forest. Elev. 350 m ASL. Latitude: 50° 38'N, Longitude: 93° 13'W.
13. Elgin, 2 km E of townsite. Habitat: Laurentian forest. Elev. 200 m ASL. Latitude: 44° 40'N, Longitude: 76° 15'W.
14. Ely, Minnesota. Habitat: Mixed woods. Elev. 200 m ASL. Latitude: 47° 58'N, Longitude: 91° 58'W.
15. Estaire, near Jct Hwys 69 and 637. Habitat: coniferous woods on shield. Elev. 200 m ASL. Latitude: 46° 15'N, Longitude: 80° 47'W.
16. Eva Lake, NW Ontario. Habitat: boreal forest. Elev. 230 m ASL. Latitude: 48° 45'N, Longitude: 91° 10'W.
17. Experimental Lakes Area, 12 km ESE of Kenora. Habitat: coniferous woods; recent burn. Elev. 123 m ASL. Latitude: 49° 39'N, Longitude: 93° 43'W.
18. Forbes, 10 km NNW of Thunder Bay. Habitat: coniferous woods. Elev. 324 m ASL. Latitude: 48° 41'N, Longitude: 89° 40'W.
19. Gowganda, 40 km N of Sudbury. Habitat: coniferous woods. Elev. 300 m ASL. Latitude: 47° 40'N, Longitude: 80° 47'W.
20. Hawkeye Lake, 20 Km NW of Thunder Bay. Habitat: coniferous woods. Elev. 250 m ASL. Latitude: 48° 39'N, Longitude: 89° 28'W.
21. High Falls, 18 km SW of Sudbury. Habitat: mixed woods. Elev. 250 m ASL. Latitude: 46° 23'N, Longitude: 81° 32'W.
22. Kaladar, Hwy 41, 1 km S Hwy 7. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 44° 51'N, Longitude: 77° 09'W.
23. Kanata, 10 km N of Pukaskwa Nat'l Park. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 45° 25'N, Longitude: 75° 25'W.
24. Killarney, 30 km SW of Sudbury. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 46° 07'N, Longitude: 81° 05'W.
25. Lac La Croix, W edge of Quetico Prov Park. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 48° 25'N, Longitude: 92° 05'W.
26. Lively-Walden, 15 km SW of Sudbury. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 46° 25'N, Longitude: 81° 10'W.
27. Manitoulin Island, 10 km N of South Baymouth. Habitat: deciduous woods. Elev. 200 m ASL. Latitude: 45° 38'N, Longitude: 82° 03'W.
28. Mattawa, 10 km E on Hwy 17. Habitat: coniferous woods on shield. Elev. 200 m ASL. Latitude: 46° 20'N, Longitude: 78° 30'W.

Table 4. continued...

29. McKellar, 5 km W of Hwy 124. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 45° 30'N, Longitude: 79° 55'W.
30. Moore Falls, near Coboconk. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 44° 50'N, Longitude: 78° 50'W.
31. Nakina, near OPP station. Habitat: coniferous woods. Elev. 320 m ASL. Latitude: 50° 11'N, Longitude: 86° 43'W.
32. Pickle Lake, 400 km NNW of Thunder Bay. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 51° 28'N, Longitude: 90° 11'W.
33. Pickwick Lake, 65 km NNE of Fort Francis. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 49° 01'N. Longitude: 93° 01'W.
34. Plastic Lake, 8 km S of Dorset, 4 km E Hwy. Habitat: coniferous woods on shield. Elev. 200 m ASL. Latitude: 45° 10'N, Longitude: 78° 50'W.
35. Port Severn, 2 km W on Hwy 5. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 44° 40'N, Longitude: 79° 45'W.
36. Pukaskwa, 60 km SW of White River. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 48° 30' N, Longitude 85° 45' W.
37. Ramsey, 1.5 km E of Ramsey. Habitat: Jack Pine-Poplar woods. Elev. 200 m ASL. Latitude: 47° 26'N, Longitude: 82° 20'W.
38. Remi Lake, 10 km N of Moonbeam. Habitat: mixed woods. Elev. 200 m ASL. Latitude: 49° 20'N, Longitude: 82° 10'W.
39. Sauble Falls, Bruce Peninsula. Habitat: coniferous woods. Elev. 150 m ASL. Latitude: 44° 50'N, Longitude: 81° 15'W.
40. Sault St. Marie, Batchawana Bay. Habitat: coniferous woods. Elev. 190 m ASL. Latitude: 46° 55'N, Longitude: 84° 35'W.
41. Smokey Falls, Mattagami River. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 50° 20'N, Longitude: 82° 00'W.
42. White River, on Hwy 17, NE of Pukaskwa Park. Habitat: coniferous woods. Elev. 200 m ASL. Latitude: 48° 40'N, Longitude: 85° 20'W.
43. Whitney, S of Algonquin Park. Habitat: coniferous woods. Elev. 412 m ASL. Latitude: 45° 28'N, Longitude: 78° 16'W.
44. Winisk, Polar Bear Provincial Park. Habitat: Tundra. Elev. 50 m ASL. Latitude: 55° 20'N, Longitude: 85° 15'W.

4.3.2. Sampling Procedure

At each site 2-3 composite bulk samples of each of the following species were collected where available:

**Cladina mitis*	(ground lichen)
**Cladina rangiferina*	(ground lichen)
†*Cladina stellaris*	(ground lichen)
†*Evernia mesomorpha*	(epiphytic lichen)
†*Hypogymnia physodes*	(epiphytic lichen)
†*Parmelia sulcata*	(epiphytic lichen)
**Pleurozium schreberi*	(feather moss)
†*Stereocaulon*	(ground lichen)
†*Tomenthypnum*	(moss)

* survey species
† special interest or only species present

Bulk lichen and moss samples of approximately 200 g each were collected into 1 litre white paper bags. Intra-site variability was minimized by combining samples from 15-20 separate colonies within a 30 m radius. These samples were combined to reduce the likelihood of obtaining biased data from a single anomalous sample and to provide an 'average' value for elemental content. This procedure provides a reliable 'average' value but no information about the range or standard deviation of values from colony to colony within a site.

Samples to be analyzed were collected by hand and extraordinary precautions were employed to prevent contamination by perspiration, insect repellents, etc. Precautionary measures included the wearing of plastic examination gloves. If the moss or lichen had to be scraped from bark or rock, they were removed with fingers or a Teflon stir rod rather than a knife. Samples were cleaned in the field to remove litter, soil, insects and accompanying cryptogamic species. The sample bags were folded over, stapled shut and labeled with site number, name, date, species, and substratum notes.

4.3.3. Sample Preparation

Two factors can alter the elemental content of samples, during or following collection, prior to analysis. First, a sample may be contaminated by the accidental incorporation or addition of extraneous substances; care must be taken to ensure that leaves, bark, twigs, insects or soil are not present in the samples. Second, elemental composition can be altered by microbial activity. Bacterial and fungal activity can be reduced by air drying the lichen and moss samples as quickly and as soon as possible.

4.3.3.1. Sample Preservation

The samples were kept in double plastic bags until they could be dried, in order to reduce the probability of contamination. They were refrigerated, but not frozen, as soon as possible after collection to minimize microbial activity. Before drying, they were cleaned a second time, if necessary, to remove any remaining litter or contaminating species. Cleaned samples were placed in open, labeled white paper bags and dried in a forced air oven for 24-48 hours at 80°C before analysis.

4.3.3.2. Grinding Method

Dried tissue was ground to pass through a 1 mm screen (40 mesh) and was collected in glass jars with plastic or pulp-lined lids. Grinding was done primarily with a stainless steel Wiley mill fitted with appropriate screens. This method was selected only after it had been shown that this method compared very well with the more time consuming method of grinding under liquid nitrogen in a chilled mortar and pestle (Section 3). The mill was cleaned between each sample and plastic gloves were worn at all times when handling the samples. Each sample jar was clearly labeled with a unique sample number on both the jar and the lid.

Samples were submitted to the Ontario Ministry of the Environment laboratory in Toronto for concentration measurements of the following 19 elements: Al, Ca, Cd, Cl, Cr, Cu, Fe, K, Mg, Mn, N, Na, Ni, P, Pb, S, Ti, V, and Zn.

4.3.4. Data Management

Chemical data had to be keyed in from OME hardcopy lab reports and verified manually. Data were validated by plotting QC plots. Gross outliers were flagged and were not included in analysis but are reported for completeness. Validated chemical analysis results data were stored on a microcomputer system.

Use of a microcomputer based data storage system provided analytical flexibility. Data could be sorted, retrieved and reported according to site, habitat, locality, latitude, longitude, species, element, sampling date, or any combination of these factors. Extracted data could be passed directly, without format conversion, to statistical analysis, plotting, and mapping programs or other computer systems via conventional long distance telephone lines or direct connection.

4.3.5. Data Analysis

4.3.5.1. Descriptive Statistics

The average, minimum, maximum and standard deviation of concentrations of each element in each species at each site was generated. Comparative bar charts were prepared showing the elemental contents of *Cladina mitis* from BGC sites according to date.

4.3.5.2. Comparative Statistics

The first step in trying to find and measure any relationships between the elemental contents of the lichen or moss samples and the available precipitation chemistry data (Kirk, 1983; Chan *et al.*, 1984) was to conduct correlation tests. Correlation coefficients were calculated for all possible combinations of elements for all the vegetation types. Scatterplots were prepared comparing element contents of *Cladina mitis*, *C. rangiferina* and *Pleurozium schreberi*.

4.3.6. Computer Mapping

Data tables provide a means of presenting the raw results of chemical determinations along with some limited descriptive statistical summaries. However, large data tables of variables and species are not conducive to data interpretation, understanding relationships between contaminant deposition and bioaccumulation, or to the visualization of geographic variability of elemental content throughout Ontario. The generation of computer contour maps was chosen as a more suitable method of showing element concentration patterns.

SURFACE II and DISSPLA were the commercially available mapping software packages used to prepare elemental content contour and isopach maps from the element concentration data. SURFACE II and DISSPLA were both running under Multics on a Honeywell Mainframe at The University of Calgary.

XYZ data files were prepared giving the north-south (Y) and east-west (X) location of the sampling site, along with the value of the parameter (Z) measured at the site. Site locations were coded as absolute horizontal and vertical distances in centimetres from the lower left-hand corner of a reference base map. If more than one measurement existed for the parameter at the same site, all XYZ records were used and an averaged value was calculated in the next step.

The XYZ data files contained values for "irregularly spaced" sites. A distance-weighted gridding procedure was used to create a regular grid matrix by interpolation from the irregularly spaced data. Grid elements were estimated by a distance weighted average of nearby sample data points. Sample data points used in the estimation procedure were weighted so their influence declines with distance from the point being estimated†. Such local fit procedures are generally considered to be the most appropriate for estimating points on a complex surface (Sampson, 1978). They are based on the intuitively appealing concept that a nearby observation is a better estimate of the value at a point on a surface than a more distant point, and that a small number of the

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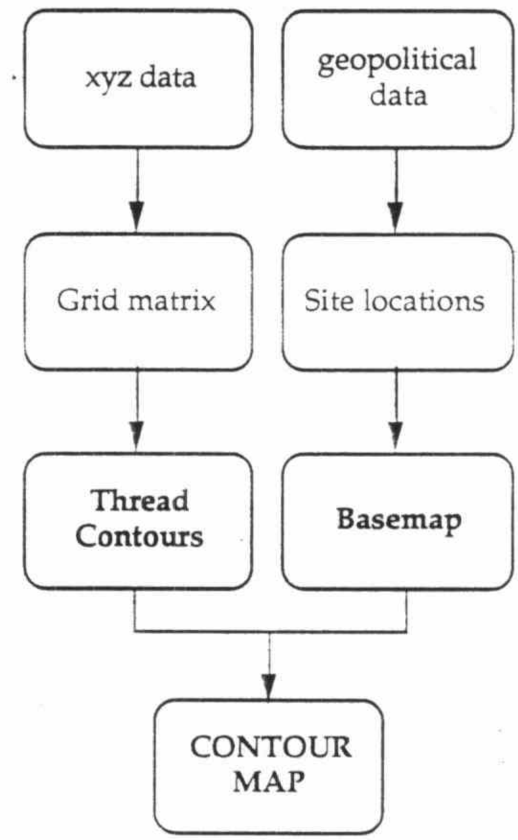
† $w = (1-(D/1.1*D_{max})^2)/(D/1.1*D_{max})^2$

where w is the weight attached to a sample data point a distance D from the grid intersection being estimated. D_{max} is the distance from the grid intersection to the most distant sample point in the set being used in the estimation.

nearest points provide essentially all of the information that is relevant in an estimate.

A typical set of steps for creating a contour map are summarized below:



Base maps were prepared on the basis of digitized maps to show the location of the sampling sites and relevant geopolitical information such provincial boundaries and major waterbodies.

The final contour maps incorporate both the base map information and the contours. They were used for visual comparison with those produced from cumulative precipitation sample chemical content and deposition data (Kirk, 1983; Chan *et al.*, 1984). Some three dimensional (3D) figures of geographic patterns in lichen element content in Ontario, are included in this report since they present the same information as the contour maps, but in a format which can present complex information in a very easy grasp format.

4.4. Results

The results of all the chemical analyses are presented in Appendix A. Summaries of elemental contents for *Cladina mitis*, *C. rangiferina*, and *Pleurozium schreberi* samples at or near APIOS monitoring sites are presented below, along with descriptive statistics. Mass concentrations of elements in lichen and moss samples showed considerable geographic variation which could be related to the proximity of power plants, smelters, other emission sources of trace elements in the Province of Ontario and local substrate effects (see discussion of seasonal variability, Section 5.6).

Typical expected elemental contents of circumboreal lichens and mosses, according to published reports in the scientific literature, are provided for comparative purposes. Geographical patterns of elemental accumulation by *C. mitis* in Ontario are illustrated by means of three dimensional (3D) figures.

Table 5. Correlation between elements in Cladina mitis

	Al	Ca	Cd	Cl	Cr	Cu	Fe	K	Mg	Mn	N	Na	Ni	P	Pb	S	Ti	V
Ca	0.254																	
Cd	0.585	0.174																
Cl	0.158	-0.084	-0.135															
Cr	0.854	0.388	0.727	-0.110														
Cu	-0.117	-0.381	0.312	-0.121	-0.004													
Fe	0.849	0.193	0.701	-0.005	0.921	0.039												
K	0.247	0.288	-0.100	-0.015	0.178	-0.191	0.131											
Mg	0.692	0.499	0.471	-0.071	0.776	-0.264	0.784	0.271										
Mn	0.321	0.578	0.193	0.023	0.258	-0.248	0.102	0.370	0.269									
N	0.055	-0.307	0.019	0.003	-0.019	0.028	-0.011	-0.197	-0.247	-0.338								
Na	0.328	0.269	0.152	0.780	0.211	-0.157	0.241	-0.051	0.325	0.105	-0.100							
Ni	-0.061	-0.337	0.434	-0.093	0.034	0.936	0.085	-0.272	-0.204	-0.193	0.061	-0.108						
P	-0.174	0.522	-0.025	-0.004	-0.092	-0.121	-0.277	0.357	-0.135	0.359	0.024	0.131	-0.140					
Pb	0.186	-0.288	0.537	-0.220	0.376	0.378	0.432	-0.234	0.129	-0.372	0.383	-0.148	0.394	-0.328				
S	0.222	0.198	0.315	-0.061	0.291	-0.051	0.385	-0.093	0.577	-0.118	-0.067	0.340	0.018	-0.232	0.284			
Ti	0.877	0.285	0.671	-0.122	0.928	-0.053	0.939	0.165	0.799	0.202	0.014	0.197	-0.038	-0.236	0.408	0.450		
V	0.618	0.057	0.445	-0.096	0.638	-0.101	0.691	-0.008	0.595	-0.003	0.109	0.107	-0.074	-0.387	0.365	0.472	0.710	
Zn	0.016	-0.140	0.045	-0.099	0.115	-0.024	0.150	0.057	0.019	-0.030	0.190	-0.169	-0.069	-0.068	0.259	0.010	0.118	0.609

Table 6. Correlation between elements in Cladina rangiferina

	Al	Ca	Cd	Cl	Cr	Cu	Fe	K	Mg	Mn	N	Na	Ni	P	Pb	S	Ti	V
Ca	0.510																	
Cd	0.030	-0.121																
Cl	0.110	0.205	-0.011															
Cr	0.110	0.213	-0.016	0.019														
Cu	0.081	-0.087	0.683	0.031	0.187													
Fe	0.802	0.358	0.211	0.093	0.197	0.280												
K	0.473	0.363	-0.045	0.334	0.080	0.159	0.411											
Mg	0.709	0.623	-0.044	0.253	0.210	0.066	0.825	0.606										
Mn	0.249	0.476	-0.044	0.258	0.276	0.184	0.201	0.445	0.402									
N	0.383	0.321	-0.038	0.195	0.018	0.100	0.288	0.680	0.357	0.173								
Na	0.406	0.519	-0.031	0.249	0.217	0.111	0.464	0.475	0.615	0.515	0.343							
Ni	0.038	-0.129	0.702	-0.016	0.400	0.921	0.210	0.070	-0.010	0.104	0.044	0.050						
P	0.272	0.439	-0.082	0.337	0.122	0.117	0.251	0.806	0.420	0.431	0.796	0.508	0.035					
Pb	0.623	0.311	0.217	0.015	0.057	0.472	0.715	0.537	0.567	0.157	0.491	0.290	0.341	0.392				
S	0.541	0.265	-0.035	0.123	-0.096	0.176	0.419	0.769	0.412	0.149	0.764	0.289	0.066	0.623	0.773			
Ti	0.914	0.404	0.056	0.073	0.086	0.112	0.907	0.441	0.777	0.160	0.385	0.420	0.055	0.268	0.750	0.570		
V	0.881	0.449	0.069	0.104	0.181	0.171	0.914	0.486	0.780	0.146	0.406	0.484	0.093	0.334	0.796	0.602	0.952	
Zn	0.483	0.267	-0.040	0.067	0.193	0.183	0.791	0.427	0.717	0.229	0.325	0.446	0.059	0.382	0.742	0.454	0.716	0.755

Table 7. Correlation between elements in Pleurozium schreberi

	Al	Ca	Cd	Cl	Cr	Cu	Fe	K	Mg	Mn	N	Na	Ni	P	Pb	S	Ti	V
Ca	0.666																	
Cd	0.419	0.257																
Cl	0.309	0.482	0.427															
Cr	0.706	0.548	0.593	0.407														
Cu	0.145	-0.057	0.667	0.186	0.227													
Fe	0.949	0.635	0.474	0.282	0.754	0.302												
K	0.525	0.378	0.767	0.569	0.624	0.467	0.520											
Mg	0.688	0.878	0.293	0.378	0.560	-0.019	0.676	0.362										
Mn	0.122	0.083	0.608	0.423	0.545	0.327	0.157	0.628	0.099									
N	0.516	0.452	0.730	0.562	0.632	0.407	0.527	0.849	0.420	0.605								
Na	0.450	0.588	0.327	0.704	0.642	-0.023	0.452	0.523	0.537	0.407	0.437							
Ni	0.114	-0.090	0.686	0.192	0.207	0.975	0.253	0.431	-0.041	0.317	0.389	-0.038						
P	0.494	0.369	0.691	0.494	0.590	0.339	0.469	0.877	0.379	0.650	0.878	0.475	0.345					
Pb	0.426	0.368	0.824	0.454	0.455	0.762	0.487	0.690	0.390	0.446	0.727	0.153	0.750	0.562				
S	0.452	0.452	0.806	0.548	0.557	0.498	0.450	0.843	0.438	0.586	0.931	0.347	0.490	0.826	0.848			
Ti	0.566	0.422	0.131	0.246	0.426	-0.012	0.534	0.246	0.385	-0.025	0.342	0.339	-0.025	0.294	0.124	0.208		
V	0.956	0.678	0.484	0.301	0.751	0.188	0.930	0.573	0.715	0.223	0.548	0.459	0.158	0.523	0.501	0.514	0.497	
Zn	0.537	0.410	0.706	0.458	0.525	0.279	0.445	0.721	0.410	0.539	0.737	0.349	0.312	0.775	0.608	0.755	0.201	0.550

Correlation coefficients for each possible pair of elements found in *C. mitis*, *C. rangiferina* and *P. schreberi* are presented in Tables 5, 6, and 7. Very significant correlations were found consistently for certain pairs of elements in all species. Examination of these tables of correlation coefficients reveals that several elements seem to travel together. For example, in the vicinity of smelters and areas with similar surficial geology, Cu contents are excellent predictors of Ni contents in all three species.

4.4.1. Aluminum (Al)

Al has been reported to be carcinogenic but to have a low degree of inherent toxicity (CGL, 1978). Recently, high levels of Al have been found in the brain tissue of human and animals with Altzheimer's and Altzheimer-like diseases. As yet, it is not known whether the high levels of Al are a symptom or are related to the cause of the disorder.

Expected Al content in lichen and moss: 200-540 µg/g dry weight (Tuominen & Jaakkola, 1973; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 310-4300 µg/g with an average content of 794 µg/g (standard deviation = 696 µg/g) in Cladina mitis; 285-2900 µg/g with an average content of 596 µg/g (standard deviation = 526.57) in C. rangiferina; and 456-2770 µg/g with an average content of 1014 µg/g (standard deviation = 622.14) in Pleurozium schreberi. The higher average content of Al in P. schreberi suggests a higher content of soil in the moss samples, even after careful cleaning. There is a significant correlation between Al and Cr, Fe Ti, and V concentrations in Cladina spp. and P. schreberi (Tables 5, 6 and 7).

The geographic pattern for Al content in *C. mitis* is illustrated in Figure 2. Al contents of *C. mitis* showed some similarity with average concentrations in precipitation in the same area (Chan *et al.*, 1984), however, the very high levels of Al found in *C. mitis* samples from SE Ontario are not reflected in these precipitation data. Since Al is associated with airborne dust and soil, it is likely that the Al content of the lichen and moss samples is principally determined by wind blown dust and run-off water. Any contribution due to Al in precipitation is obscured. Al contents of *C. rangiferina* and *P. schreberi* were similar to those of *C. mitis* (Figures 3 and 4)

4.4.2. Arsenic (As)

Arsenic is highly toxic and teratogenic. It has also been reported to be carcinogenic (CGL, 1978).

Expected As content in lichen and moss: 0.1-1.15 µg/g (dry weight). (LeBlanc *et al.*, 1974; Steinnes, 1977).

Observed to date: 0.30-2.18 µg/g with an average content of 0.36 µg/g (standard deviation = 0.31) in *C. rangiferina* and 0.30 µg/g (standard deviation = 0.51) in *P. schreberi*. There were too few measurements of As to permit reliable mapping or the identification of regional trends. The data available fall within the range measured in *C. rangiferina*.

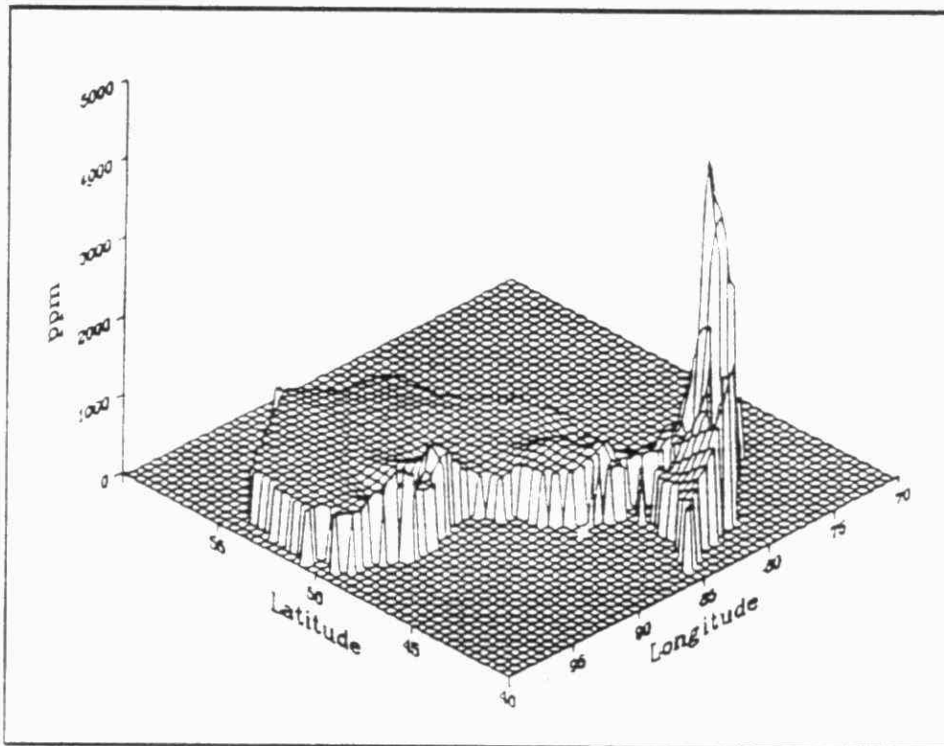


Figure 2. Geographic pattern of Al content in *C. mitis*.

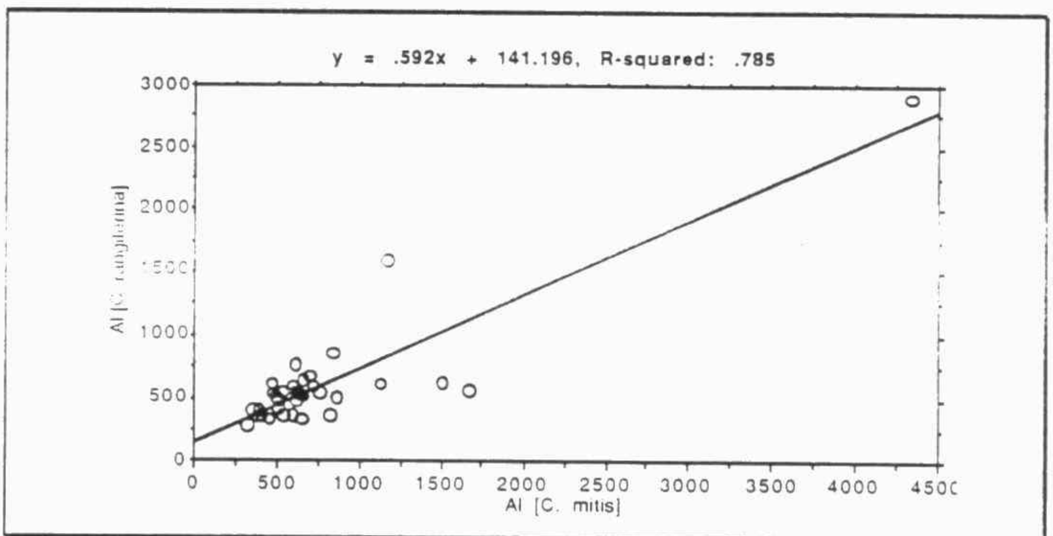


Figure 3. Al contents of *C. rangiferina* and *C. mitis* collected at the same sites.

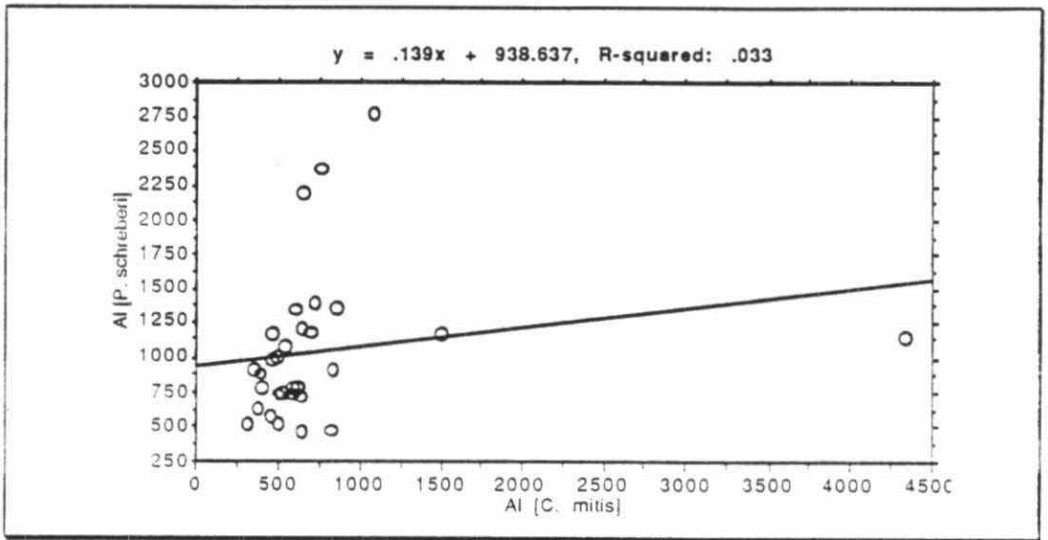


Figure 4. Al contents of *C. mitis* and *P. schreberi* collected at the same sites.

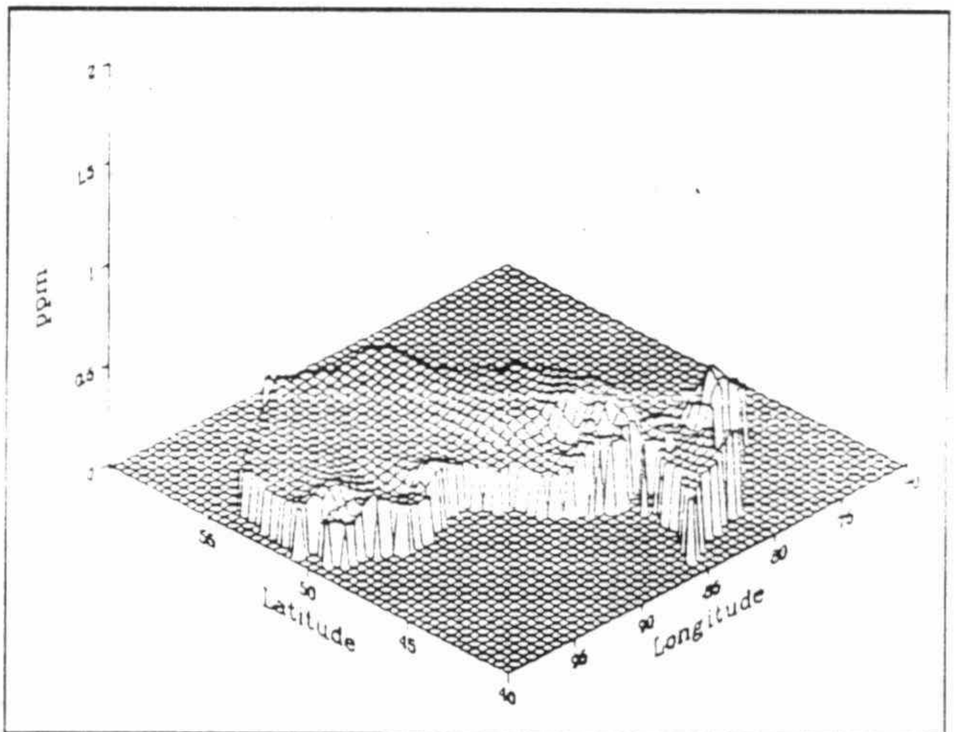


Figure 5. Geographic pattern of Cd content in *C. mitis*.

4.4.3. Cadmium (Cd)

Cd is highly carcinogenic, mutagenic, clastogenic, and teratogenic (Sawicki, 1978). It is moderately toxic to mammals and highly toxic to vegetation (CGL, 1978; Nieboer *et al.*, 1977). Exposure to Cd causes changes in the distribution and metabolism of Zn.

Expected Cd content in lichen and moss: 1-30 µg/g (dry weight) (Nash, 19[illegible]; Nieboer *et al.*, 1978; Steinnes, 1977; Case, 1982).

Observed to date: 0.15-0.60 µg/g with an average content of 0.29 µg/g (standard deviation = 0.1) in *C. mitis*; 0.14-0.60 µg/g with an average of 0.30 µg/g (standard deviation = 0.1) in *C. rangiferina*; and 0.30-1.3 µg/g with an average of 0.61 µg/g (standard deviation = 0.27) in *P. schreberi*.

The geographic pattern of Cd content in *C. mitis* is illustrated in Figure 5. Cd levels in *C. mitis* were somewhat similar to *C. rangiferina*, but not correlated with *P. schreberi* (Figures 6 and 7). Elevated levels of Cd in the lichen samples occurred in regions which had precipitation with higher average annual concentrations of Cd (Chan *et al.*, 1984). Studies (Glooschenko *et al.*, 1988; MNR, 1987a, b) have reported Cd accumulation in liver and kidney of moose and deer in areas which had elevated levels in *C. mitis*.

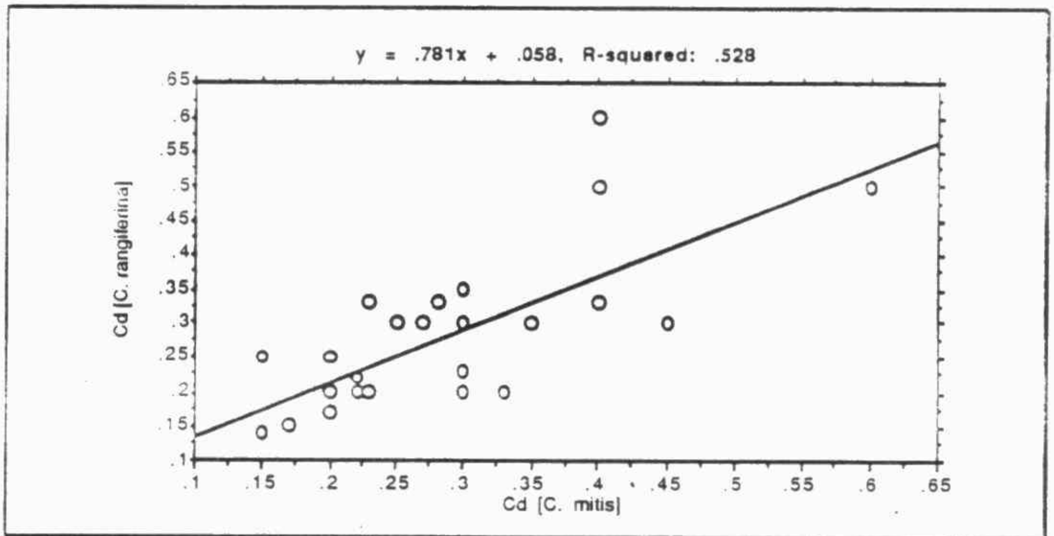


Figure 6. Cd contents of *C. rangiferina* and *C. mitis* collected at the same sites.

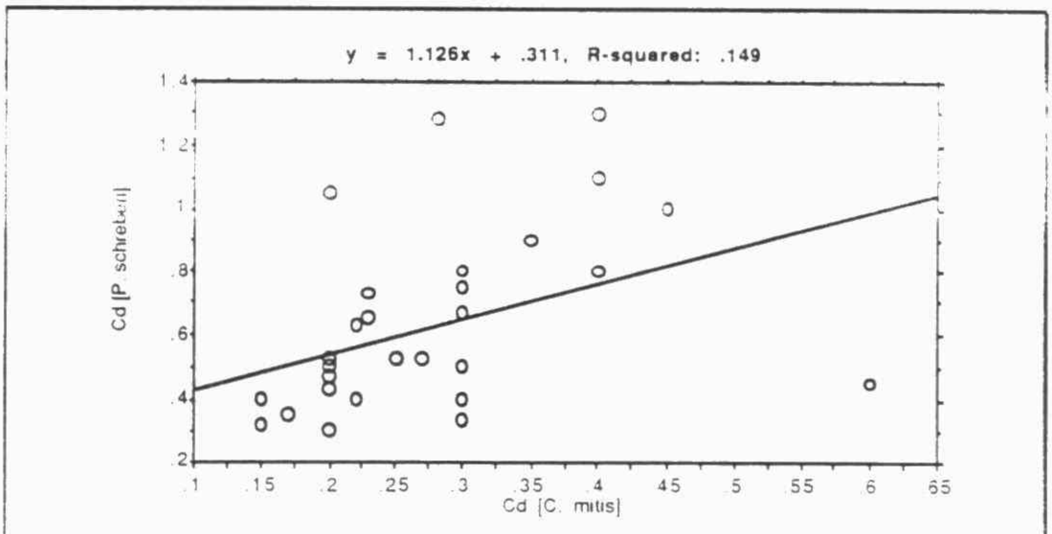


Figure 7. Cd contents of *C. mitis* and *P. schreberi* collected at the same sites.

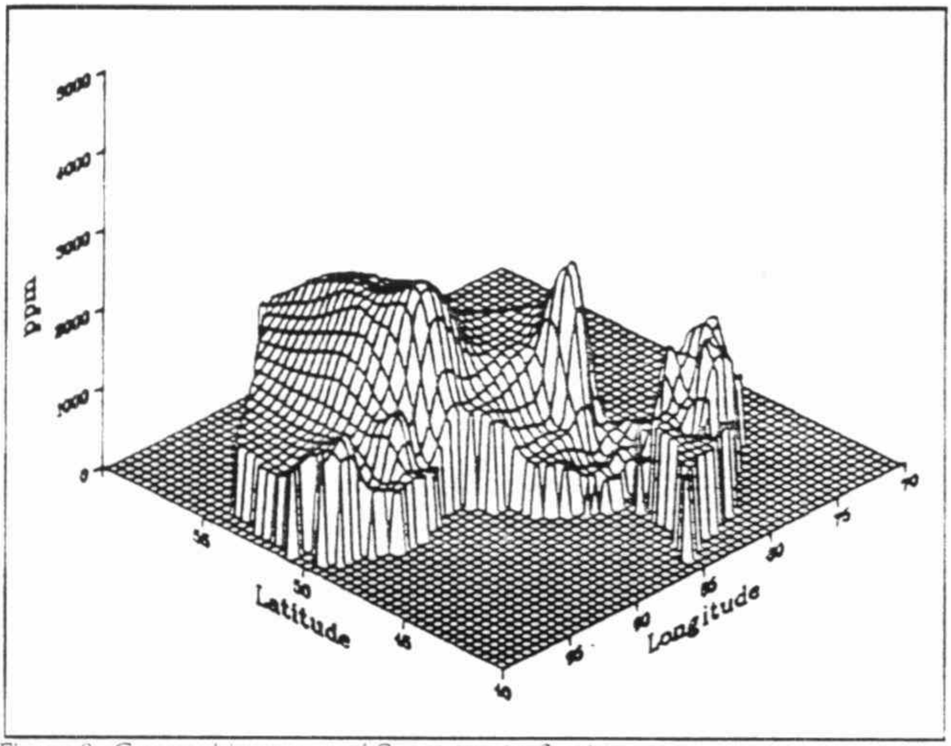


Figure 8. Geographic pattern of Ca content in *C. mitis*.

4.4.4. Calcium (Ca)

Expected Ca content in lichen and moss: 200-40,000 µg/g (dry weight) (Scotter, 1972; Kuziel, 1973; Kovács-Láng & Verseghy, 1974; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 250-2640 µg/g with an average content of 966 µg/g (standard deviation = 514) in *C. mitis*; 346-2990 µg/g with an average of 1052 µg/g (standard deviation = 649) in *C. rangiferina*; and 2080-18,450 µg/g with an average of 5094 µg/g (standard deviation = 3284) in *P. schreberi*.

The geographic pattern of Ca content in *C. mitis* is illustrated in Figure 8. The Ca content of *C. mitis* showed little similarity with that of average annual Ca content or annual deposition due to precipitation (Kirk, 1983; Chan *et al.*, 1984).

Ca levels in *C. mitis* were significantly correlated with those of *C. rangiferina* (Figure 9), and to a lesser extent, with those of *P. schreberi* (Figure 10).

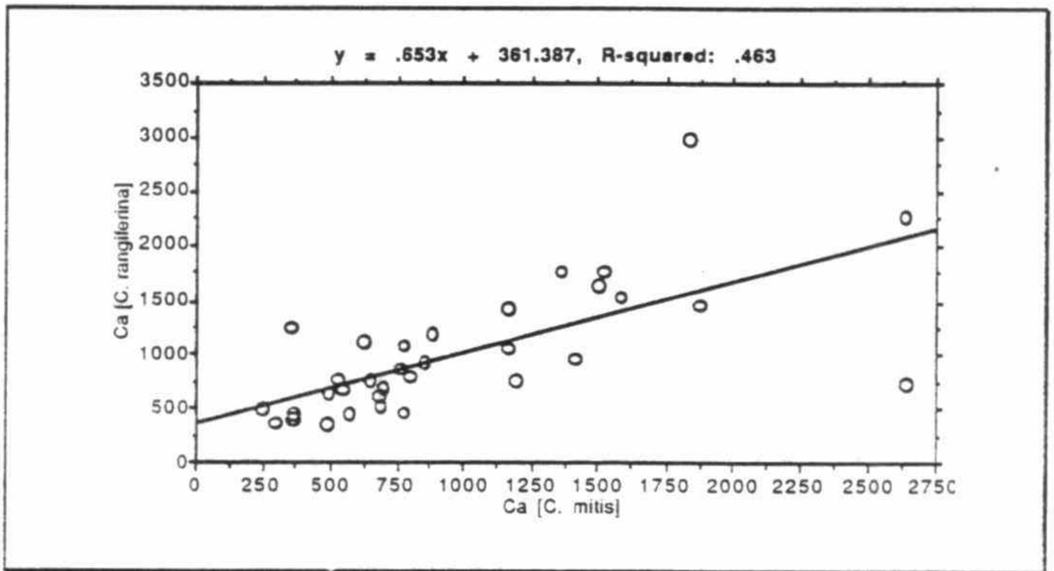


Figure 9. Ca contents of *C. rangiferina* and *C. mitis* collected at the same sites.

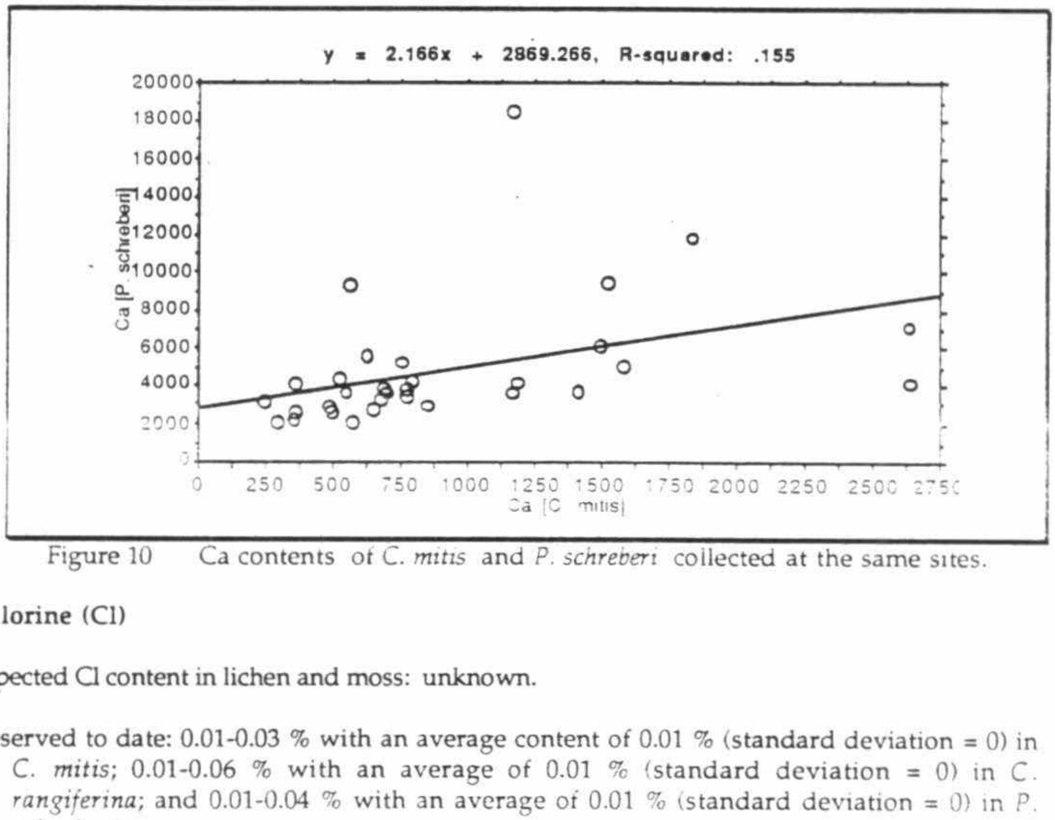


Figure 10 Ca contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.5. Chlorine (Cl)

Expected Cl content in lichen and moss: unknown.

Observed to date: 0.01-0.03 % with an average content of 0.01 % (standard deviation = 0) in *C. mitis*; 0.01-0.06 % with an average of 0.01 % (standard deviation = 0) in *C. rangiferina*; and 0.01-0.04 % with an average of 0.01 % (standard deviation = 0) in *P. schreberi*.

The method used to determine the sample Cl content was not sufficiently sensitive. As a result, many of the results were near the detection limit. No meaningful concentration pattern for Cl could be prepared. The data available did not suggest any relationship between the contents of Cl in *C. mitis*, *C. rangiferina* (Figure 11) and *P. schreberi* (Figure 12).

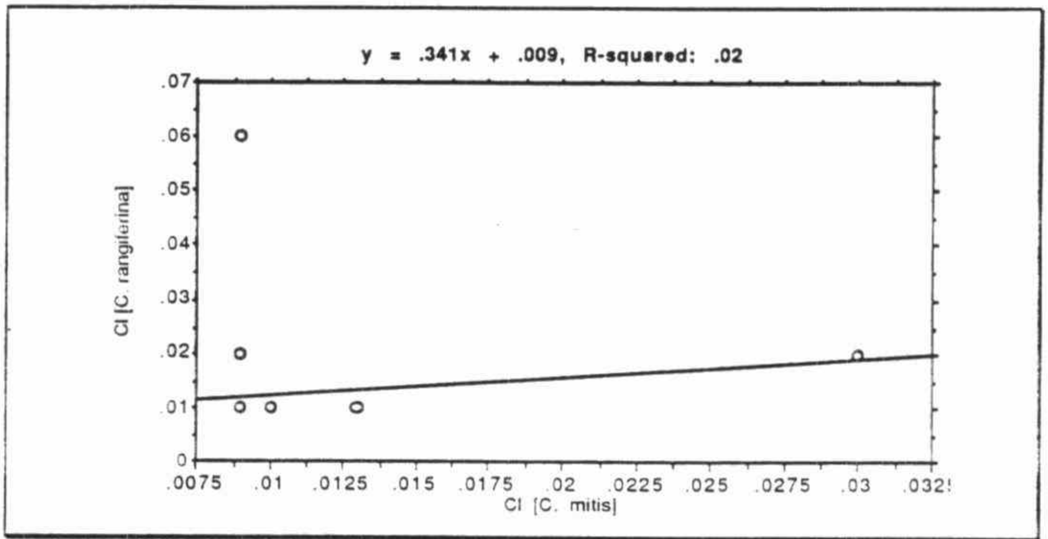


Figure 11. Cl contents of *C. rangiferina* and *C. mitis* collected at the same sites.

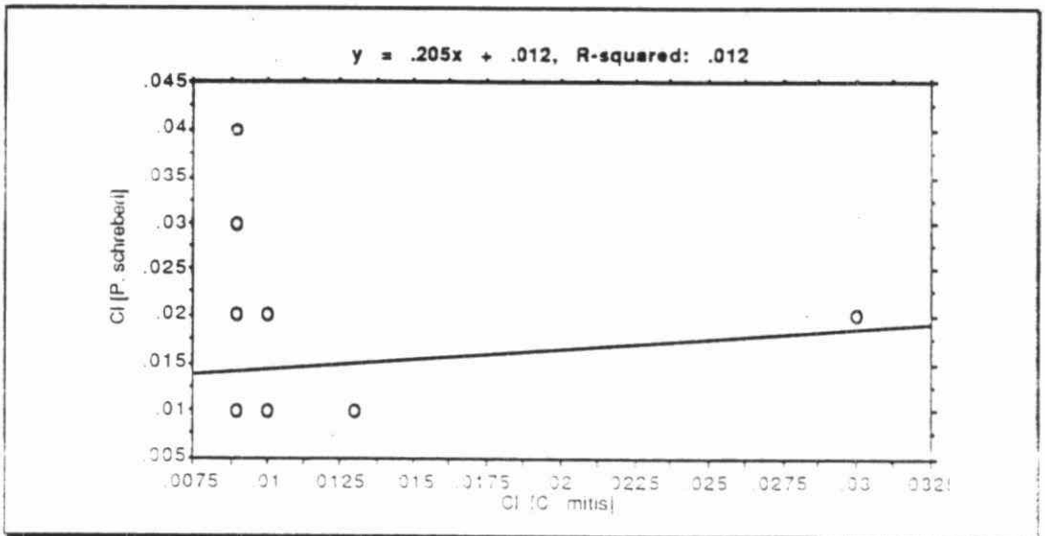


Figure 12. Cl contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.6. Chromium (Cr)

Cr is highly carcinogenic and mutagenic (Sawicki, 1978). Acute and chronic adverse effects are caused mainly by hexavalent compounds which are very toxic. Inhalation of hexavalent Cr compounds has been linked to the development of bronchial carcinomas and adenocarcinomas.

Expected Cr content in lichen and moss: 0.0-10 μg/g (dry weight) (Leroy & Koksov, 1962; Tomassini, 1976; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 0.90-6.00 μg/g with an average content of 1.86 μg/g (standard deviation = 0.99) in *C. mitis*; 0.90-11.00 μg/g with an average of 2.08 μg/g (standard deviation = 1.01) in *C. rangiferina;* and 1.0-6.5 μg/g with an average of 3.58 μg/g (standard deviation = 1.40) in *P. schreberi* .

The geographic pattern of Cr content in *C. mitis* is shown in Figure 13. The region of apparently high concentration centred around Peterborough-Campbellford is the result of several high values. The elevated levels of Cr detected may be a function of increased densities of urbanization and industrialization. Elevated Cr levels were not detected in mining and smelting areas. The Cr

contents of *C. rangiferina* showed some similarity to those of *C. mitis* (Figure 14), however, the Cr contents of *P. schreberi* were not correlated with those of *C. mitis*.

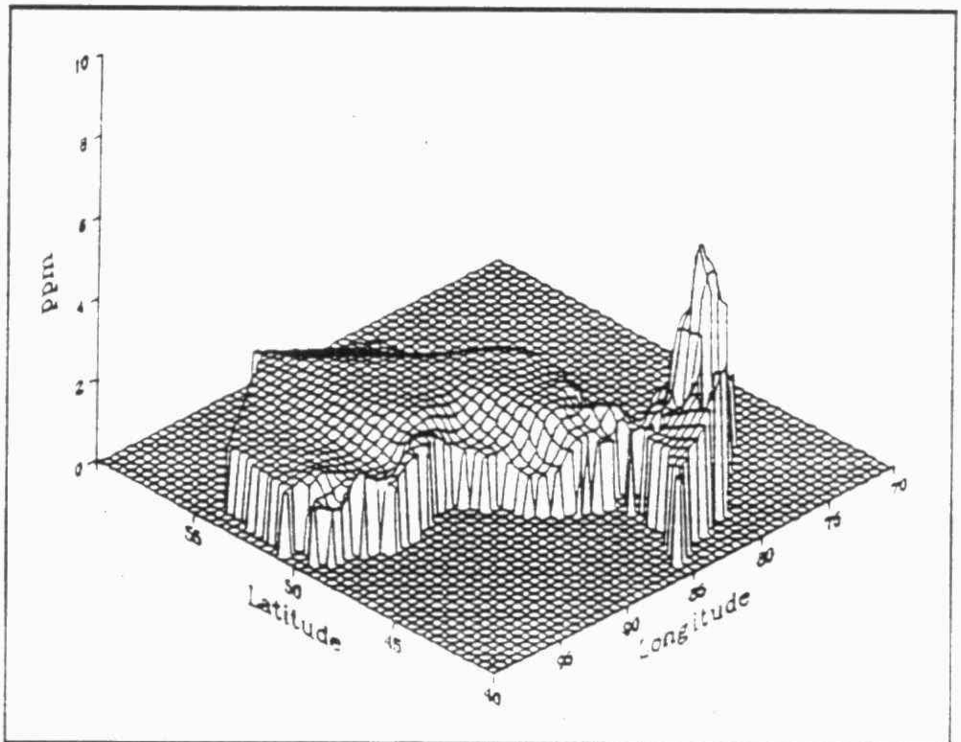


Figure 13. Geographic pattern of Cr content in *C. mitis*.

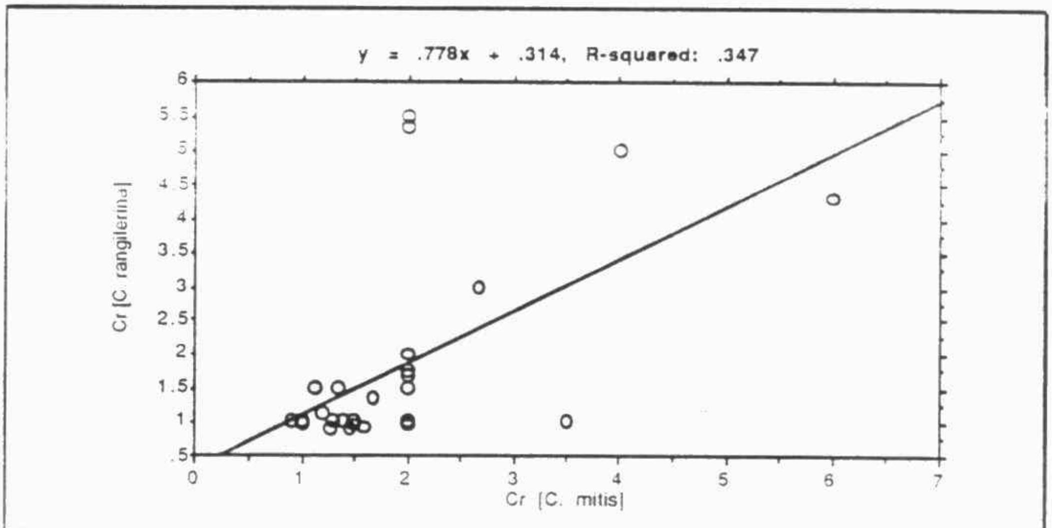


Figure 14. Cr contents of *C. rangiferina* and *C. mitis* collected at the same sites.

4.4.7. Copper (Cu)

Cu is carcinogenic and mutagenic (Sawicki, 1978). It is highly toxic to vegetation but only somewhat toxic to mammals (CCL, 1978; Nieboer *et al.*, 1977).

Expected Cu content in lichen and moss: <1-15 µg/g (dry weight) (Steinnes, 1977; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982; Martin & Coughtrey, 1982).

Observed to date: 1.00-25.00 µg/g with an average content of 4.69 µg/g (standard deviation of 5.70) in *C. mitis*; 1.50-24.50 µg/g with an average of 4.65 µg/g (standard deviation = 4.96) in *C. rangiferina*; and 3.33-76.00 µg/g with an average of 11.99 µg/g (standard deviation = 16.97) in *P. schreberi*.

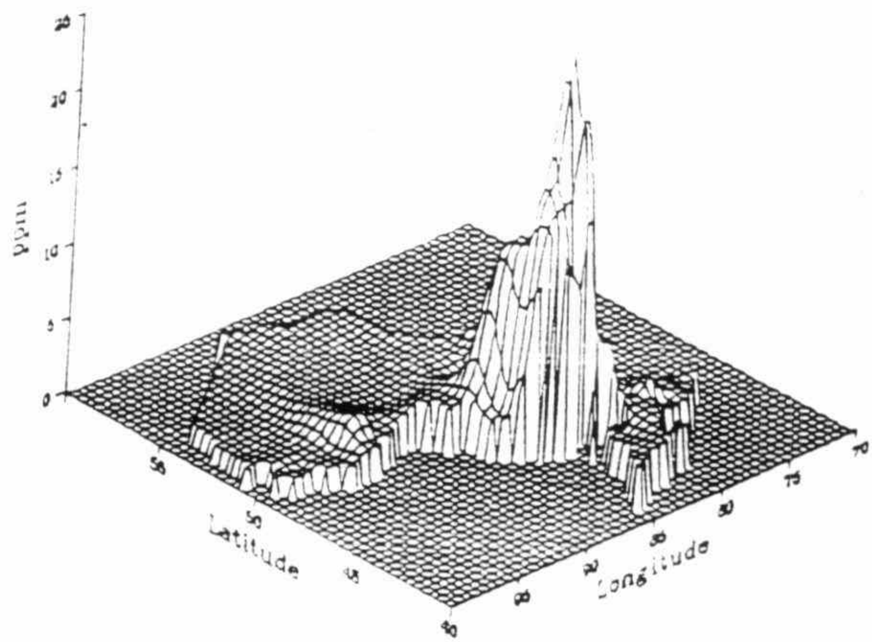


Figure 15. Geographic pattern of Cu content in *C. mitis*.

The geographic pattern of Cu content in *C. mitis* is shown in Figure 15. Cu analysis results for *C. mitis* revealed a region of highly elevated accumulation in central Ontario, relative to that measured in remote regions. The region of greatest Cu bioaccumulation is associated with the Sudbury area. This region of elevated Cu contents extended over most of NE Ontario. Cu levels in *C. mitis* were significantly correlated with those of *C. rangiferina* (Figure 16), and to a lesser but still significant extent, with those of *P. schreberi* (Figure 17).

Cu levels in the lichens may reflect availability of the metal from exposed rock of the Canadian Shield. Correlation analysis of bioaccumulation with average concentrations in precipitation (Kirk, 1983; Chan *et al.*, 1984) revealed no significant relationships. The pattern of regional Cu content in lichen and moss samples showed no positive correlation with that of annual Cu concentration or annual deposition due to precipitation (Kirk, 1983; Chan *et al.*, 1984).

Cu is biologically very active and plays a significant role in several physiological processes in plants; photosynthesis, respiration, carbohydrate distribution, N reduction and fixation, protein metabolism, DNA and RNA production, and cell wall metabolism. Cu also controls water relationships indirectly via its effect on xylem wall permeability. There is some evidence that plants with enriched Cu concentrations are susceptible to some diseases (Kabata-Pendias & Pendias, 1984). The Cu content of cryptogamic species at many sites in the region of greatest accumulation are at levels associated with toxicity symptoms in vascular plants.

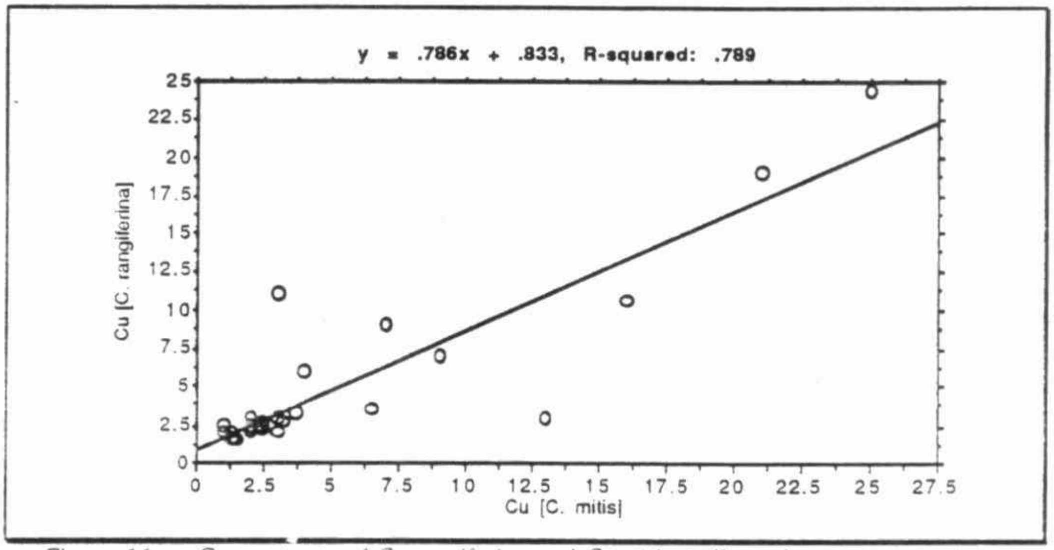


Figure 16. Cu contents of *C. rangiferina* and *C. mitis* collected at the same sites.

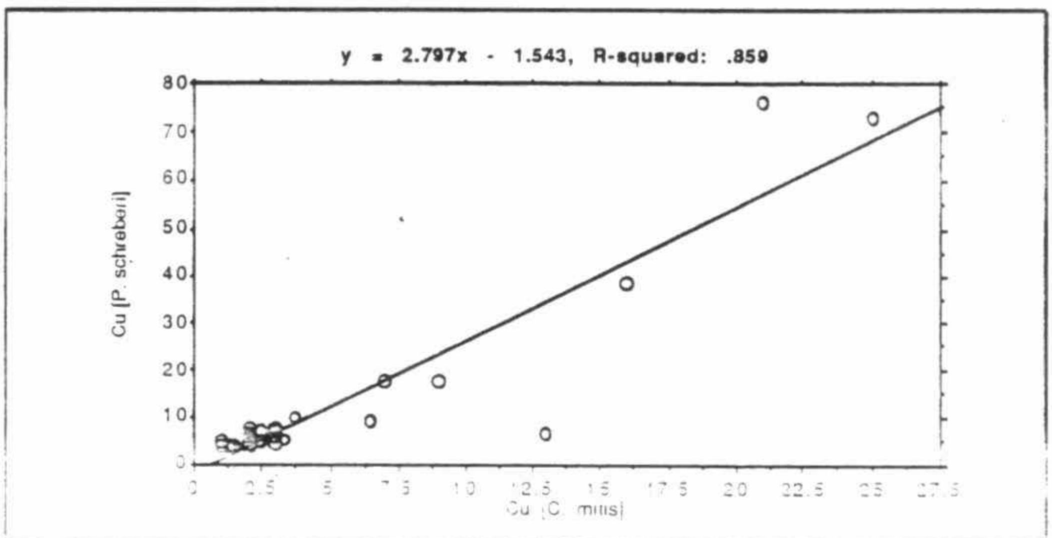


Figure 17. Cu contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.8. Iron (Fe)

Fe is reported to be carcinogenic and co-carcinogenic (Sawicki, 1978) but has a low degree of inherent toxicity (CGL, 1978). In some cases, the level of Fe found in the samples collected was more than four times the maximum allowable for government registered complete feeds (i.e., 750 µg/g).

Expected Fe content in lichen and moss: 50-1600 µg/g (dry weight) (Steinnes, 1977; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982; Martin & Coughtrey, 1982).

Observed to date: 330-3640 µg/g with an average content of 981.87 µg/g (standard deviation = 706.7) in *C. mitis*; 317-4180 µg/g with an average of 864 µg/g (standard deviation = 741.3) in *C. rangiferina;* and 475-3276 µg/g with an average of 1361 µg/g (standard deviation = 766.37) in *P. schreberi*.

The geographic pattern of Fe content in *C. mitis* is shown in Figure 18. Analysis results for *C. mitis* revealed a region of highly elevated Fe accumulation associated with the Peterborough-Campbellford region of SE Ontario. Two secondary regions of Fe accumulation were revealed in the Sudbury and Dorion regions. Fe content of the *Cladina* species were well correlated (Figure 19) but

P. schreberi Fe contents were not correlated with that of *C. mitis* (Figure 20). The concentration pattern of Fe contents of *C. mitis* show some similarity with Fe concentration of acidic precipitation (Chan, 1984). As in the case of precipitation (Kirk, 1983; Chan *et al.*, 1984), Fe levels in *C. mitis* are elevated in the vicinity of Nakina, Mattawa and throughout extreme SE and S Ontario, and in NE Ontario, downwind of the Sudbury region.

Fe compounds are greatly involved in the behaviour of some macro-nutrients and of many trace elements. Also, bioactive elements are known to influence the bioavailability of Fe, which is itself a micronutrient. Almost all instances of Fe deficiency in plants are considered to occur because of soil factors that govern Fe solubility. Fe toxicity is not common.

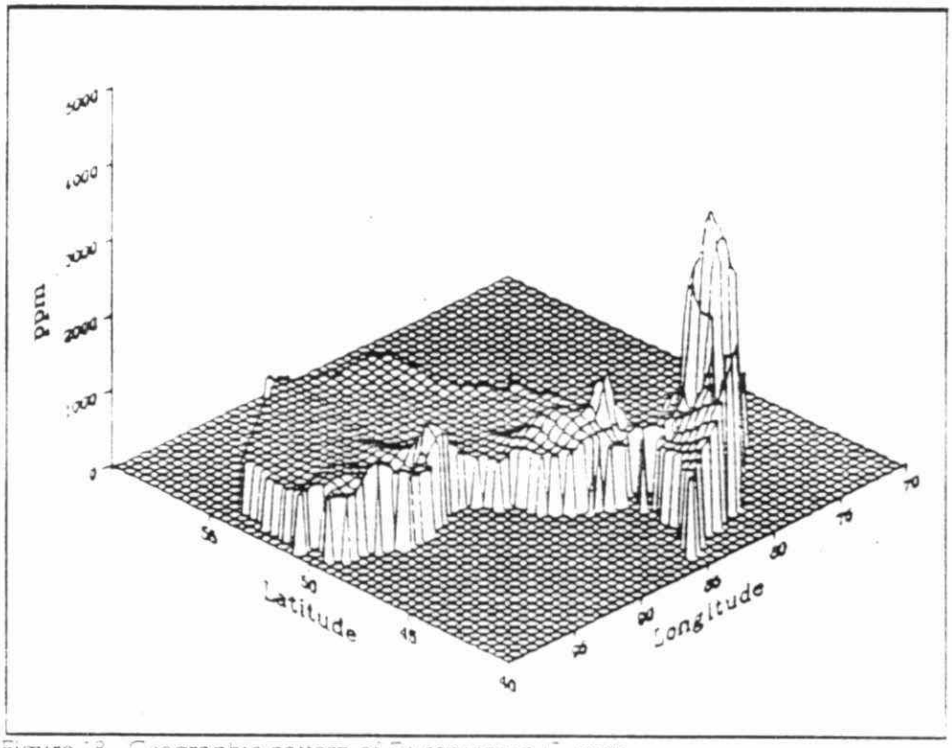


Figure 18. Geographic pattern of Fe content in *C. mitis*.

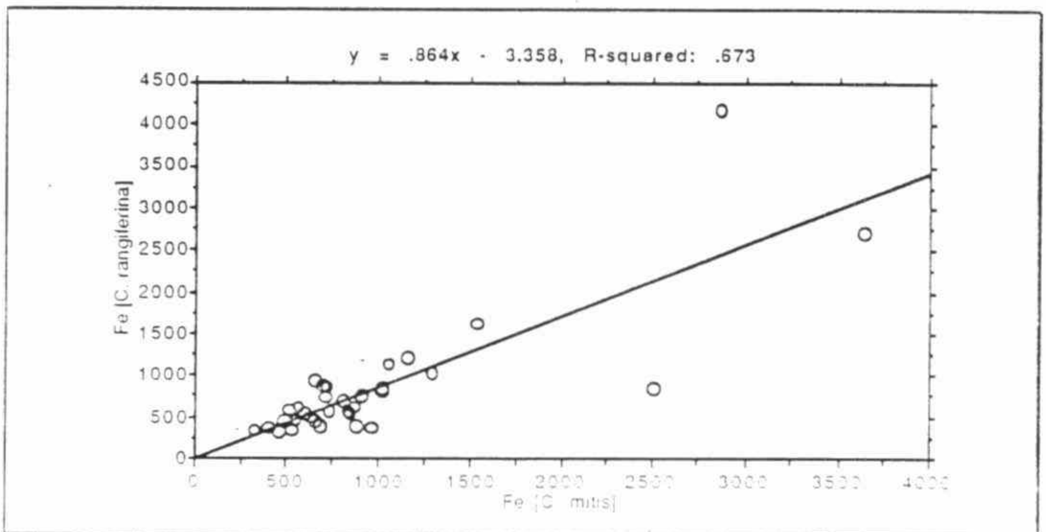


Figure 19. Fe contents of *C. mitis* and *C. rangiferina* collected at the same sites.

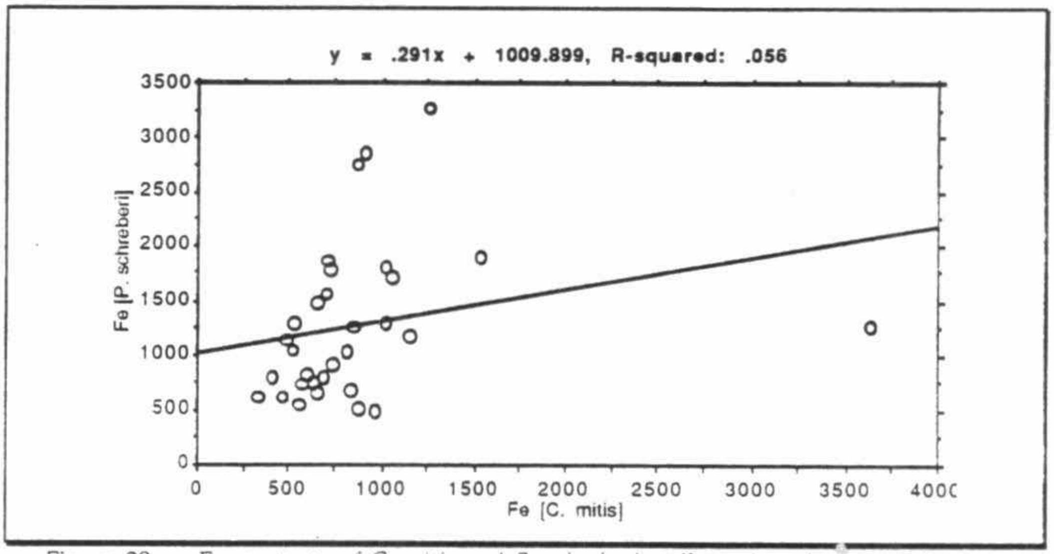


Figure 20. Fe contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.9. Lead (Pb)

In addition to being toxic, Pb compounds are carcinogenic and/or mutagenic. They interfere with the ability of DNA molecules to select the correct bases during replication (Sawicki, 1978). The lowest quantity of lead in food capable causing chronic illness is not known, but 10 µg/g dry matter is generally accepted figure for animals (Underwood, 1973).

Expected Pb content in lichen and moss: 0-10 µg/g (dry weight) (LeBlanc *et al.*, 1974; Grodzinska, 1978; Glooschenko & Capobianco, 1978; Barclay-Estrup & Rinne, 1978; Furr *et al.*, 1979; Rinne & Barclay-Estrup, 1980; Steinnes, 1977, 1980; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Burkitt *et al.*, 1982; Case, 1982).

Observed to date: 5.5-31.0 µg/g with an average content of 13.9 µg/g (standard deviation = 6.9) in *C. mitis*; 4.0-43.0 ug/g with an average of 14.7 ug/g (standard deviation = 8.4) in *C. rangiferina*; and 9.5-71.0 µg/g with an average of 25.1 ug/g (standard deviation = 13.6) in *P. schreberi*. Note that all these species have average Pb contents which would probably be undesirable for forage.

The geographic pattern of Pb content in *C. mitis* is shown in Figure 21. The Pb concentration increased in areas of urbanization. Pb levels in *C. mitis* were similar to those of *C. rangiferina* (Figure 22), and with those of *P. schreberi* (Figure 23). The figures indicate that the Pb levels in *C. mitis*, *C. rangiferina*, and *P. schreberi* are correlated. The concentration pattern of Pb in *C. mitis* is very similar to the pattern of annual Pb deposition from precipitation (Kirk, 1983; Chan *et al.*, 1984).

Assuming it is not coincidental, the similarity of Pb bioaccumulation and the pattern of Pb content in precipitation can be interpreted as being indicative of a common atmospheric source for the Pb in precipitation and cryptogams, or that the cryptogams acquire Pb primarily from precipitation. It is likely that the lichens and mosses acquire Pb from both sources.

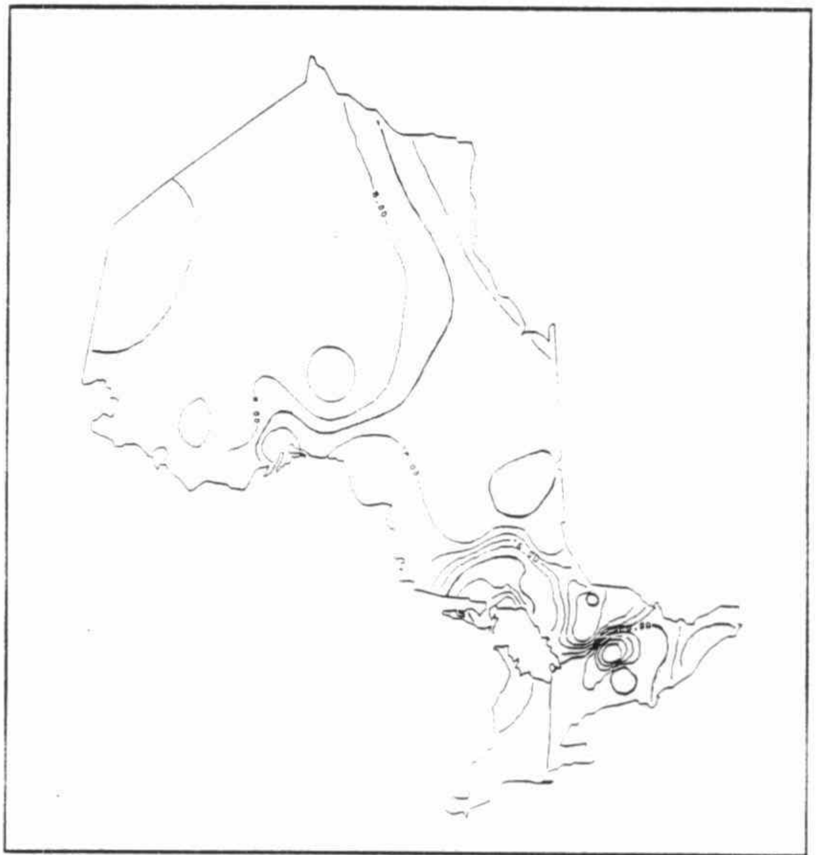


Figure 21. Geographic pattern of Pb content in *C. mitis*

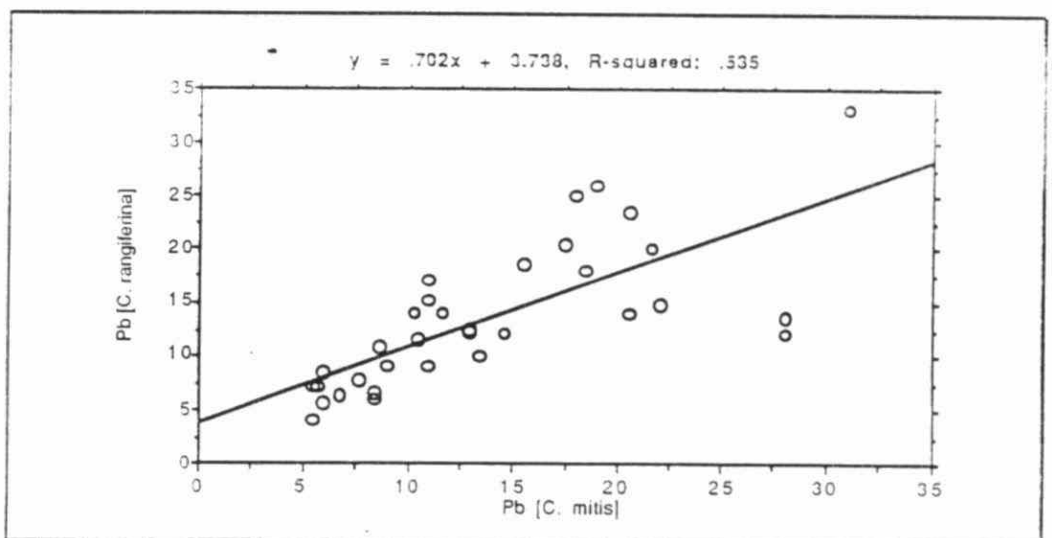


Figure 22. Pb contents of *C. mitis* and *C. rangiferina* collected at the same sites.

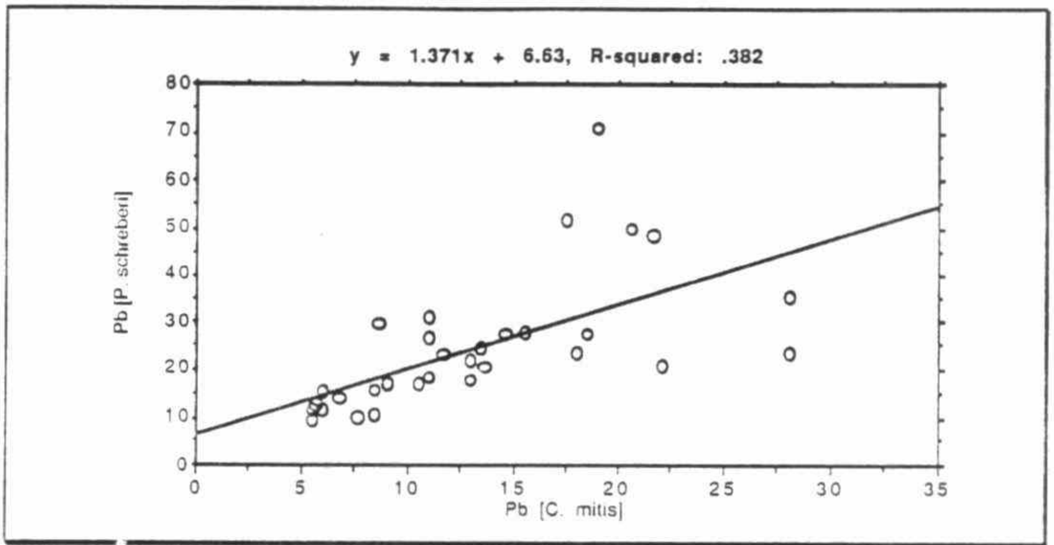


Figure 23. Pb contents of *C. mitis* and *P. schreberi* collected at the same sites.

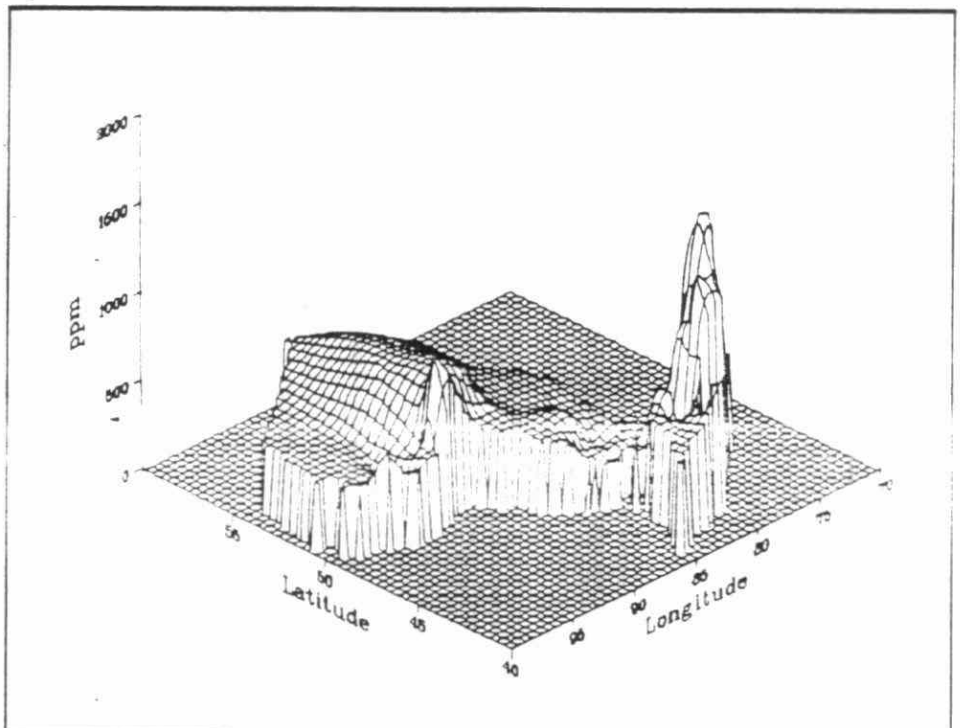


Figure 24. Geographic pattern of Mg content in *C. mitis*.

4.4.10. Magnesium (Mg)

Expected Mg content in lichen and moss: 100-1000 µg/g (dry weight) (Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 205-1460 µg/g with an average content of 453 µg/g (standard deviation = 289.3) in *C. mitis*; 210-1260 µg/g with an average of 420 µg/g (standard deviation = 224.5) in *C. rangiferina*; and 620-6760 µg/g with an average of 1343 µg/g (standard deviation = 1086.5) in *P. schreberi*.

The geographic pattern of Mg content in *C. mitis* is shown in Figure 24. The highest concentrations of Mg in *C. mitis* were found in SE Ontario, in the vicinity of Clarendon and Dummer. A second small increase extends northward from the north shore of Lake Superior. Mg levels in *C. mitis* and *C. rangiferina* were related (Figure 25). Those of *P. schreberi* (Figure 26) showed little similarity with Mg levels in *C. mitis*.

Computation of correlation coefficients between average precipitation Mg levels and bioaccumulator contents revealed no significant relationships with any bioaccumulator species. However, comparison with the patterns of annual deposition of Mg due to precipitation (Kirk, 1983; Chan *et al.*, 1984) revealed some similarities.

Mg is one of a small group of trace elements (also including Ca and P) which has antagonistic impacts on the absorption and metabolism of such toxic elements as Al, Be, Ba, Cr, Mn, F, Zn, Ni, Co, Cu, and Fe. It is also occasionally synergistic to beneficial or protective characteristics of Al and Zn.

The significance of the Mg levels that were higher than expected is not clear. In some cases, the level of Mg found in the samples approached the maximum allowable for government registered complete feeds (5000 µg/g).

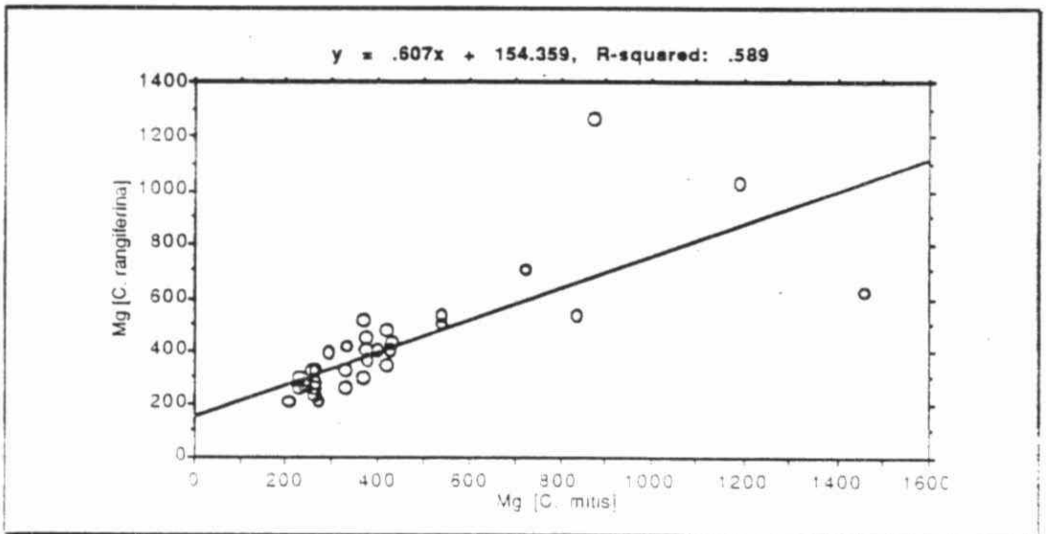


Figure 25. Mg contents of *C. mitis* and *C. rangiferina* collected at the same sites.

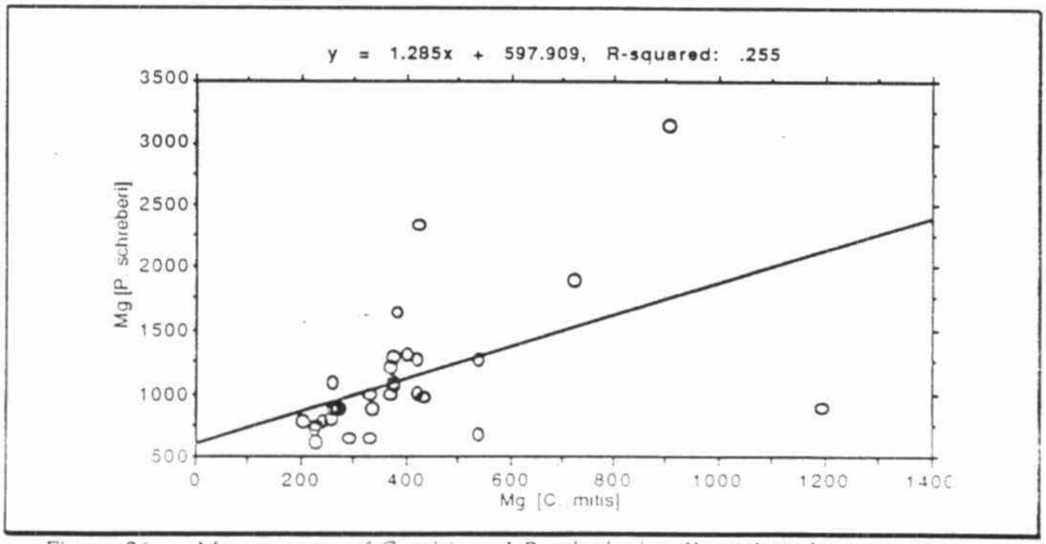


Figure 26. Mg contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.11. Manganese (Mn)

Mn is slightly carcinogenic but has a low degree of inherent toxicity (CGL, 1978). Chronic brain disease can occur after exposure to Mn oxides in mines or ore processing plants where levels exceed 50 mg/m^3 (Friberg *et al.*, 1979). In some cases, the level of Mn found in the samples collected was more than four times the maximum allowable for government registered complete feeds (i.e., 200 µg/g).

Expected Mn content in lichen and moss: 10-130 µg/g (dry weight) (Grodzinska, 1978; Nieboer *et al.*, 1978; Rinne & Barclay-Estrup, 1980; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 19.5-132.5 µg/g with an average content of 51.5 µg/g (standard deviation = 29.2) in *C. mitis;* 18.5-135.5 µg/g with an average of 60.31 µg/g (standard deviation = 30.8) in *C. rangiferina;* and 48-818.5 µg/g with an average of 339.7 µg/g (standard deviation = 188.5) in *P. schreberi*.

The geographic pattern of Mn content in *C. mitis* is shown in Figure 27. The pattern is similar in extent, if not degree, to that of Mg in *C. mitis*. The Mn contents of *C. rangiferina* are similar to those of *C. mitis* (Figure 28). Mn levels in *P. schreberi* were not significantly correlated with those of either *Cladina* species.

Mn concentration in precipitation (Kirk, 1983; Chan *et al.*, 1984) shows no significant correlation with bioaccumulator Mn contents. Examination of the patterns of Mn content of precipitation (Chan *et al.*, 1984) revealed no apparent similarity with the patterns of Mn levels in *C. mitis*.

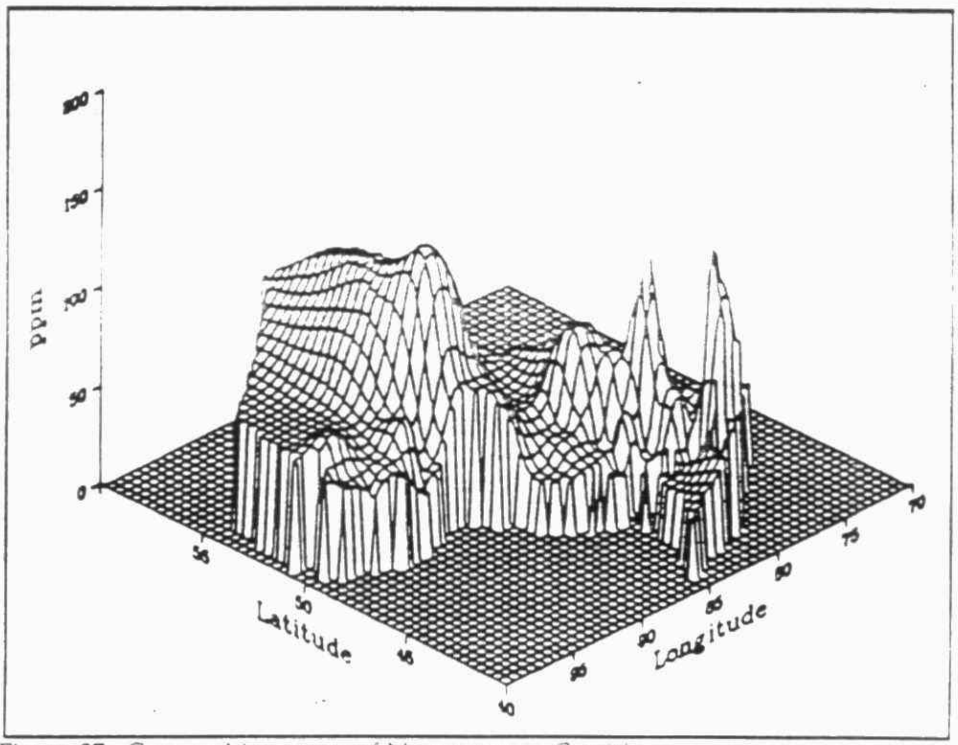


Figure 27. Geographic pattern of Mn content in *C. mitis*.

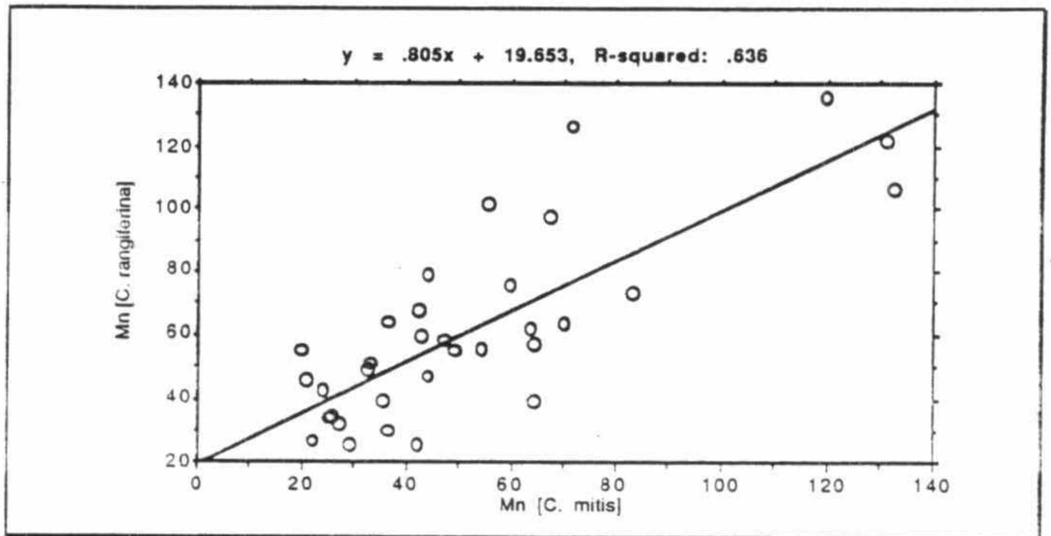


Figure 28. Mn contents of *C. mitis* and *C. rangiferina* collected at the same sites.

4.4.12. Mercury (Hg)

Hg contents of carpet-forming mosses in isolated regions of Norway, ecologically similar to northern Ontario, average 0.13 µg/g (Steinnes, 1977). Mosses in Alaska also have average Hg contents of about 0.13 µg/g and individual sample levels as low as 0.01 µg/g (Siegel *et al.*, 1975). Ground lichens from the same region had average contents of 0.02 µg/g (Siegel *et al.*, 1975).

In addition to being toxic, Hg is reported to be carcinogenic and co-carcinogenic (Sawicki, 1978).

Expected Hg content in lichen and moss: 0.02-0.15 µg/g (dry weight) (Huckabee, 1973; Ruhling & Tyler, 1973; Mondano & Smith, 1974; Wallin, 1976; Pakarinen and Tolonen, 1976; Nieboer *et al.*, 1978; Solberg and Selmer-Olsen, 1978; Lodenius & Laaksovirta, 1979; Furr *et al.*, 1979; Rinne & Barclay-Estrup, 1980; Steinnes, 1977, 1980; Bosserman and Hagner, 1981; Lodenius, 1981; Case, 1982).

Observed to date: 0.03-0.21 µg/g with an average of 0.07 µg/g (standard deviation = 0.05) in *C. rangiferina*; and 0.05-0.14 µg/g with an average of 0.09 µg/g (standard deviation = 0.03) in *P. schreberi*. There were too few measurements made for *C. mitis* but the available values fall within the range for *C. rangiferina*.

Mercury contents of *C. rangiferina* and *P. schreberi* were measured in samples from about one third of the APIOS lichen and moss study sites. The highest levels of Hg found were to be about 2 to 3 times the average concentration. These high values may be associated with mining activity or natural variation of Hg soil content.

4.4.13. Nickel (Ni)

Ni is highly carcinogenic and mutagenic (Sawicki, 1978). It is moderately toxic to mammals and highly to moderately toxic to plant life (CGL, 1978; Nieboer *et al.*, 1977).

Expected Ni content in lichen and moss: 0-5 µg/g (dry weight) (Pakarinen & Tolonen, 1976; Tomassini, 1976; Tomassini *et al.*, 1976; Grodzinska, 1978; Nieboer *et al.*, 1978; Rinne & Barclay-Estrup, 1980; Case, 1982).

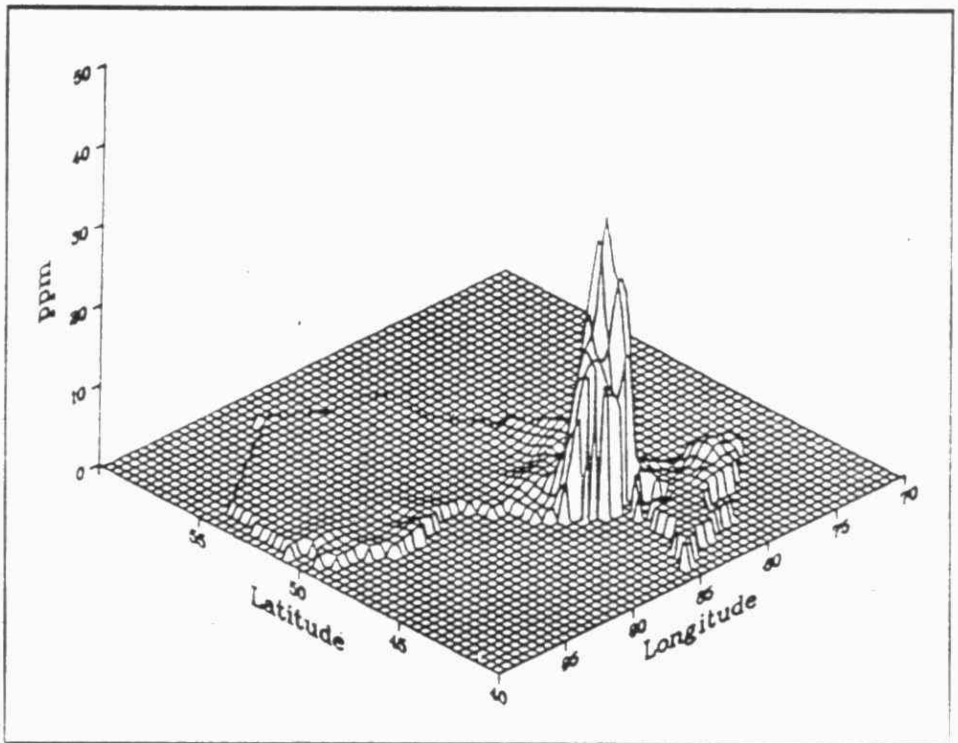


Figure 29. Geographic pattern of Ni content in *C. mitis*.

Observed to date: 0.93-34.5 µg/g with an average content of 4.4 µg/g (standard deviation = 7.6) in *C. mitis*; 0.9-33.0 µg/g with an average of 4.4 µg/g (standard deviation = 7.0) in *C. rangiferina*; and 1.7-81.0 µg/g with an average of 9.6 µg/g (standard deviation = 17.8) in *P. schreberi*.

The geographic pattern of Ni content in *C. mitis* is shown in Figure 29, which reveals an area of greatly increased Ni content associated with the Sudbury region. This pattern is very similar to the one for Cu content in the same species. As in the case of Cu, the Ni content of *C. mitis* is correlated with that of *C. rangiferina* (Figure 30) and *P. schreberi* (Figure 31) sampled at the same site.

No contour maps of the average annual concentration of Ni in precipitation or deposition due to precipitation were available in Chan *et al.* (1984) because the content of this element in precipitation samples was usually at the detection limit. This suggests that the cryptogams get a very small proportion of their Ni from precipitation. Rather, the principal source of Ni is likely particulate matter which quickly drops out of the air or water in direct contact with metal containing rock.

4.4.14. Nitrogen (N)

Expected N content: unknown

Observed to date: 3.65-7.3 mg/g with an average content of 5.62 mg/g (standard deviation = 0.98) in *C. mitis*; 4.1-16.9 mg/g with an average of 6.36 mg/g (standard deviation = 2.25) in *C. rangiferina*; and 6.35-14.1 mg/g with an average of 9.6 mg/g (standard deviation = 2.1) in *P. schreberi*.

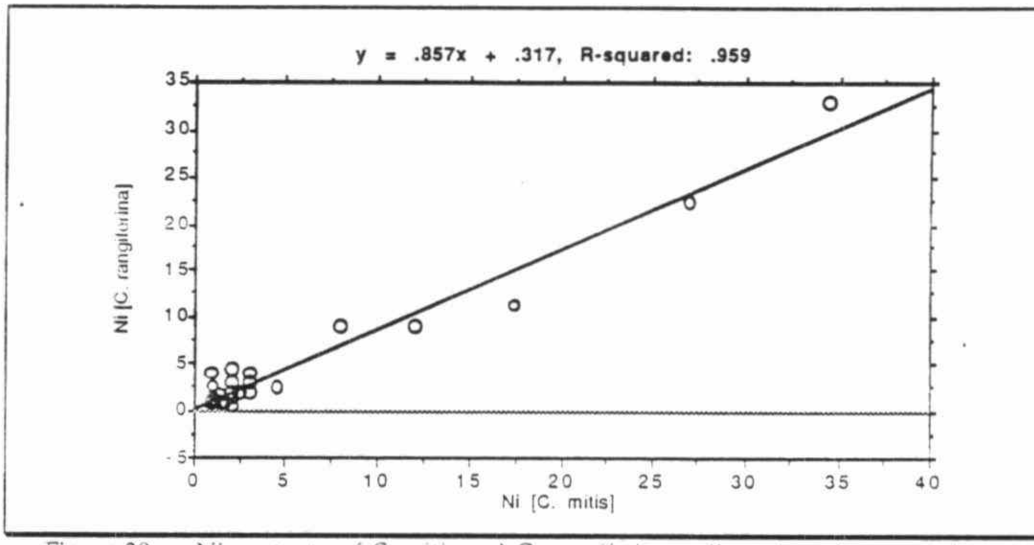


Figure 30. Ni contents of *C. mitis* and *C. rangiferina* collected at the same sites.

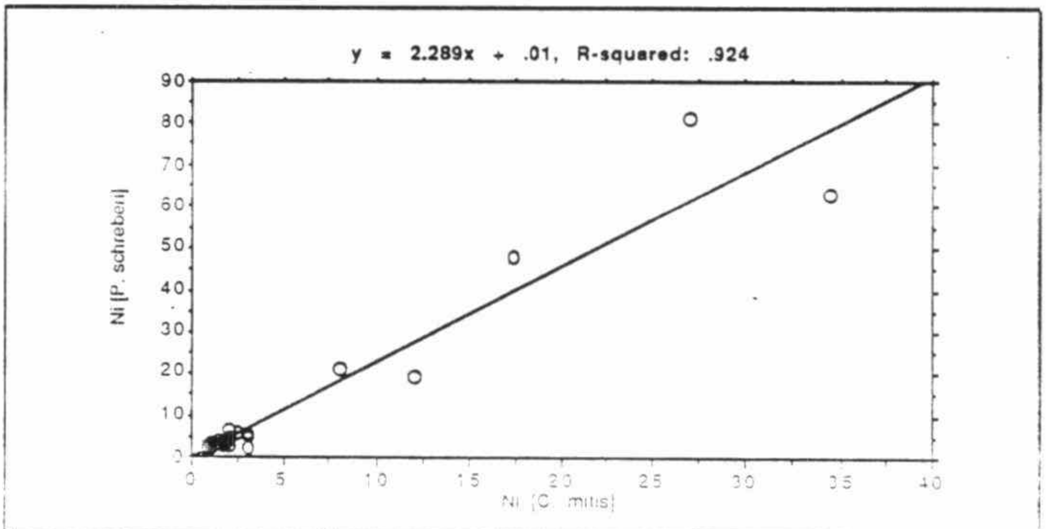


Figure 31. Ni contents of *C. mitis* and *P. schreberi* collected at the same sites.

The geographic pattern of N content in *C. mitis* is shown in Figure 32. There is a general negative south to north concentration gradient, with the high concentrations being in southern Ontario. The highest total N contents of *C. mitis* were detected in the remote regions of NW and NE Ontario. A region of depressed N content was found between Sudbury and Timmins. The concentration patterns of N levels in *C. rangiferina* (Figure 33) and *P. schreberi* (Figure 34) show little similarity with those of *C. mitis*.

The pattern of N content in *C. mitis* is somewhat similar to that of N-TKN (nitrogen-total Kjeldahl nitrogen) annual deposition, and N-NH_4^+ annual deposition (Chan *et al.*, 1984).

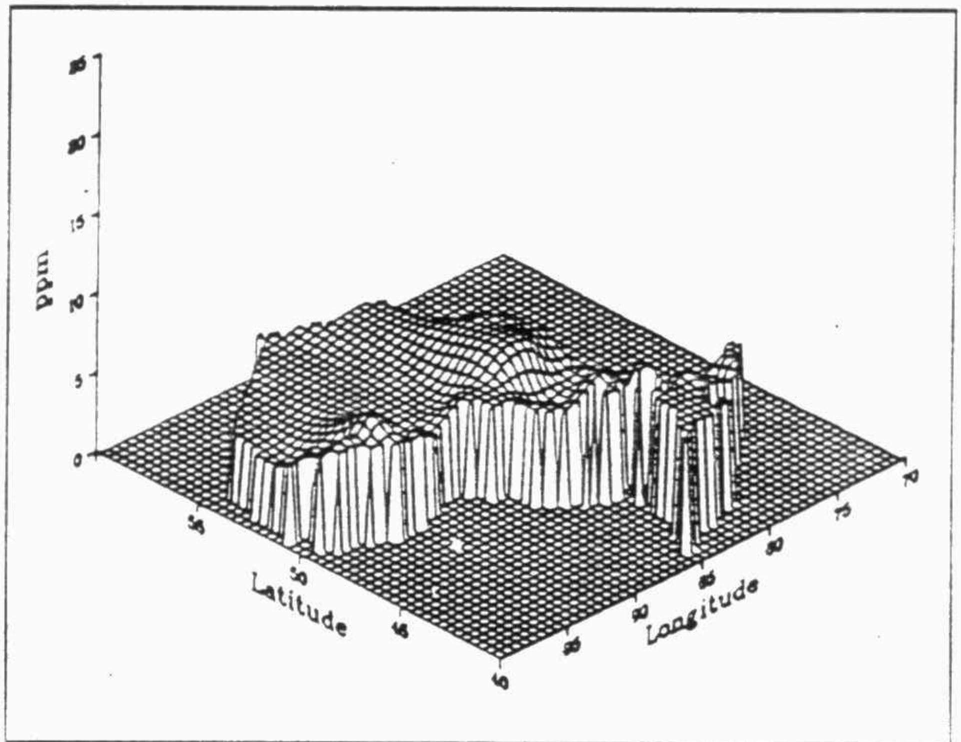


Figure 32. Geographic pattern of N content in *C. mitis*

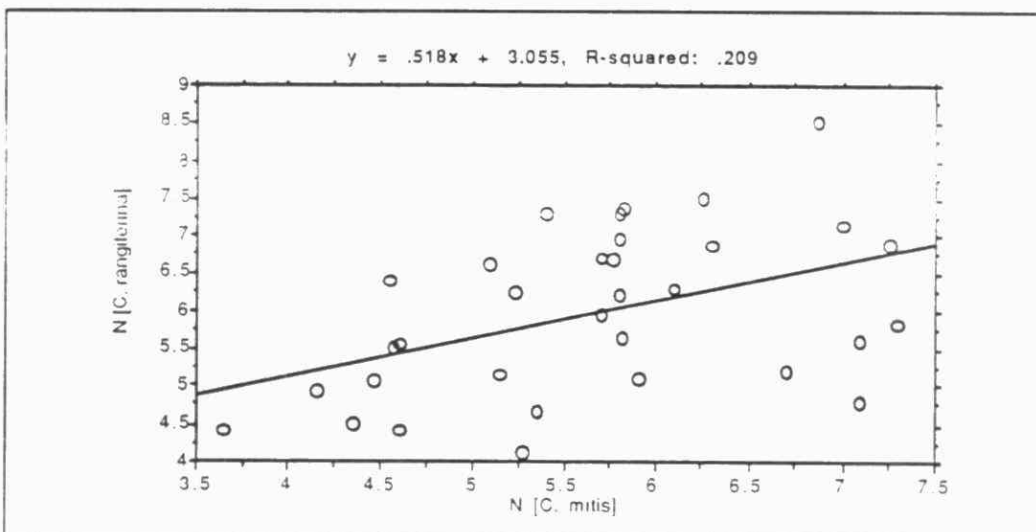


Figure 33. N contents of *C. mitis* and *C. rangiferina* collected at the same sites.

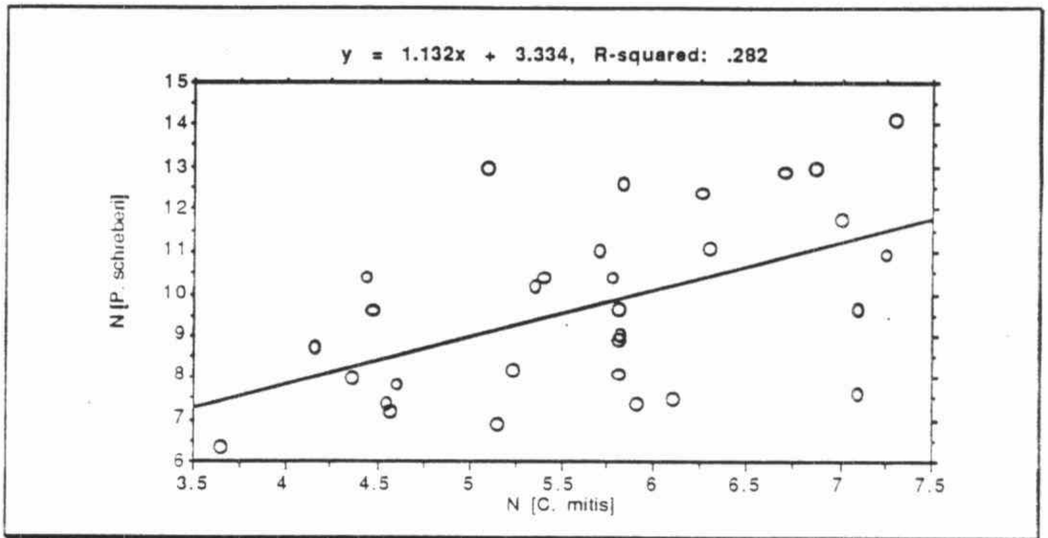


Figure 34. N contents of *C. mitis* and *P. schreberi* collected at the same sites.

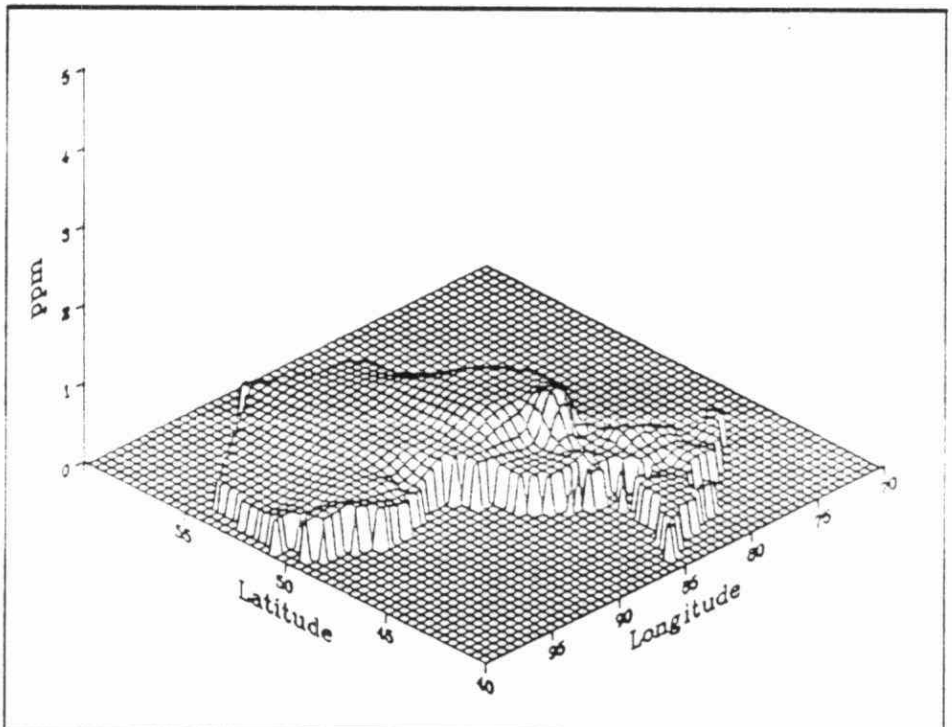


Figure 35. Geographic pattern of P content in *C. mitis*

4.4.15. Phosphorous (P)

Expected P content in lichen and moss: 0.2-2.0 mg/g (dry weight) (Nieboer *et al.*, 1978; Case, 1982).

Observed to date: 0.3-1.0 mg/g with an average content of 0.45 mg/g (standard deviation = 0.14) in *C. mitis*; 0.3-0.95 mg/g with an average of 0.55 mg/g (standard deviation = 0.15) in *C. rangiferina*; and 0.45-1.90 mg/g with an average of 1.01 mg/g (standard deviation = 0.3) in *P. schreberi*.

The geographic pattern of P content in *C. mitis* is shown in Figure 35. The figure reveals a fairly uniform P content in *C. mitis* throughout Ontario with the exception of the Sudbury region, where P contents appear to be depressed in an area where levels of Cu and Ni were highest in *C. mitis*. P levels in *C. mitis* and *C. rangiferina* showed some similarity (Figure 36). There was much less similarity between *C. mitis* and *P. schreberi* P levels (Figure 37). P concentrations in *C. mitis* showed no relationship with annual P-PO_4 average concentration in precipitation or annual deposition due to precipitation (Kirk, 1983; Chan *et al.*, 1984).

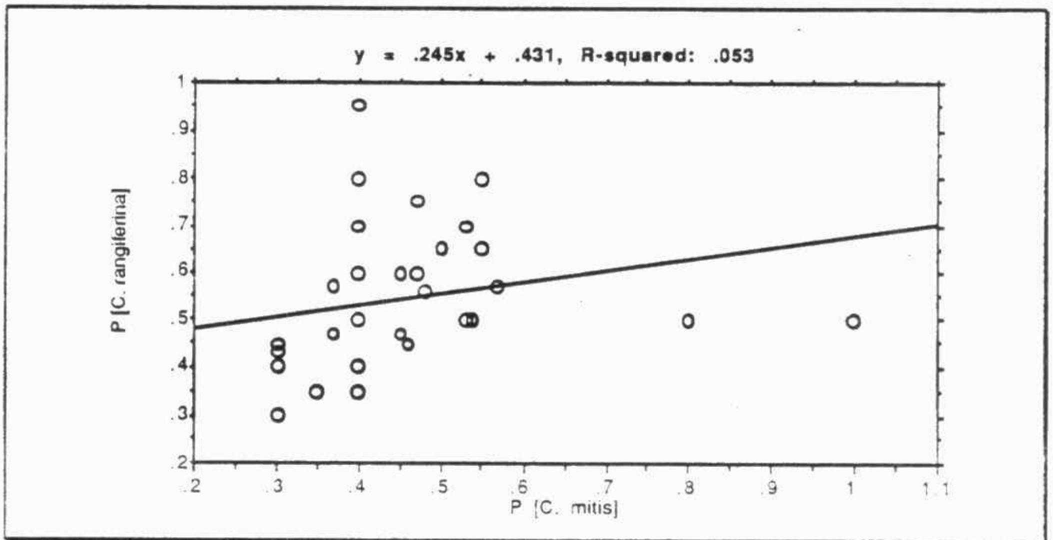


Figure 36. P contents of *C. mitis* and *C. rangiferina* collected at the same sites.

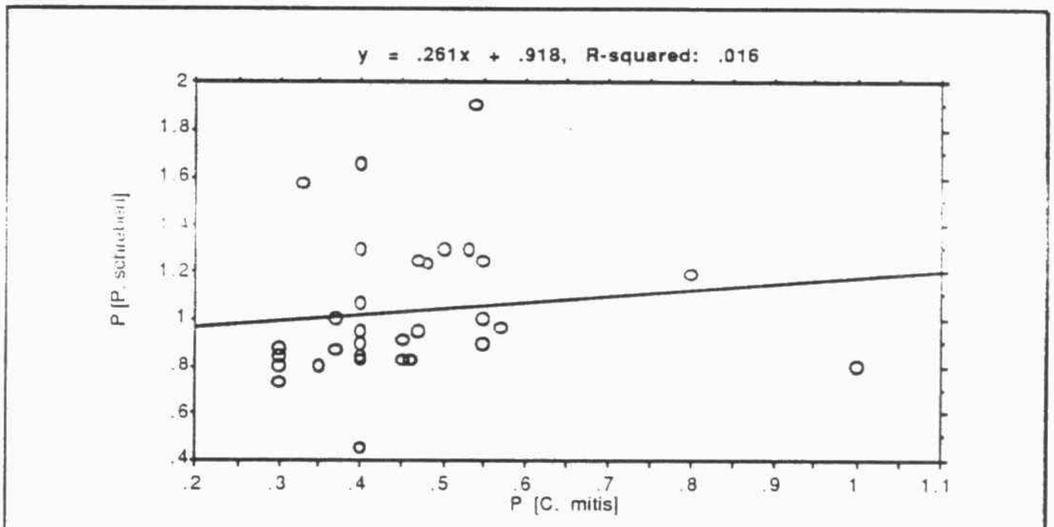


Figure 37. P contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.16. Potassium (K)

Expected K content in lichen and moss: 500-5000 µg/g (dry weight) (Bertrand & Bertrand, 1947; Yarilova, 1947; Wöhlbier & Lindner, 1959; Micovic & Stefanovic, 1961; Mäkelä, 1976; Scotter & Miltimore, 1973; Kuziel, 1973; Kovács-Láng & Verseghy, 1974; Steinnes, 1977; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 0.11-0.25 % with an average content of 0.16 % (standard deviation = 0.03) in *C. mitis*; 0.13-0.26 % with an average of 0.18 % (standard deviation = 0.03) in *C.*

rangiferina; and 0.34-0.73 % with an average of 0.48 % (standard deviation = 0.10) in *P. schreberi*.

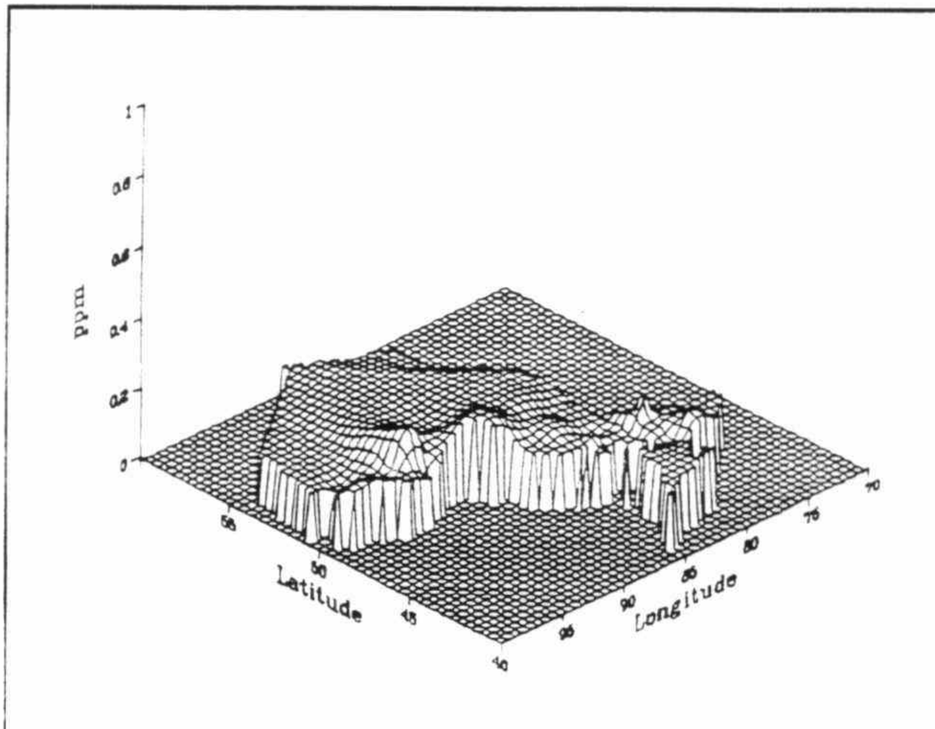


Figure 38. Geographic pattern of K content in *C. mitis*.

The geographic pattern of K content in *C. mitis* is shown in Figure 38. K analysis results for *C. mitis* revealed little variability in content throughout the province. There is some indication of slightly elevated levels near White River and Quetico. K contents of *C. mitis*, *C. rangiferina*, and *P. schreberi* were not significantly correlated. Examination of precipitation annual average K concentration and deposition patterns (Kirk, 1983; Chan *et al.*, 1984) revealed little if any similarity between bioaccumulation and precipitation chemistry.

The region of highest K content in *C. mitis* was associated with the Dorset-Campbellford region of SE Ontario. Two secondary regions of elevated K content were found in the Sudbury and Dorion regions. K contents of the *Cladina* species are significantly related but K contents of *P. schreberi* were not correlated with those of *C. mitis*. Also, the K contents of the cryptogams are not significantly correlated with precipitation K content. However, precipitation K contents are elevated in SE Ontario and in NE Ontario, downwind of the Sudbury region (Kirk, 1983; Chan *et al.*, 1984).

K is essential for the normal growth and development of virtually all living organisms. In higher plants, it is the most abundant cation and the fifth most abundant element behind C, H, O, and N. However, unlike these elements, K does not occur as part of any stable organic compounds, but rather it is present as the extremely mobile free monovalent cation (K^+). It is also the most mobile nutrient element and is found in phloem sap at high concentrations.

4.4.17. Selenium (Se)

The genotoxic properties of Se in its various forms and compounds are highly controversial. In dispute are the reported anticarcinogenic, carcinogenic, clastogenic and teratogenic properties of this essential element. A number of diseases caused by Se deficiency have been reported in animals.

Several studies have indicated that diets containing 5 µg/g or more cause chronic selenosis in several species of animals; this level is generally accepted as the dividing line between toxic and non-toxic feeds (NAS, 1976). There is also evidence that Se compounds may efficiently protect animals from toxic concentrations of Th, Cd, Ag, Hg and methyl-Hg. The level of Se in some samples analyzed exceeded the maximum allowable for government registered complete feeds.

Expected Se content in lichen and moss: 0.05-1.10 µg/g (dry weight) (Steinnes, 1977).

Observed to date: 0.03-0.79 µg/g with an average of 0.31 µg/g (standard deviation = 0.25) in *C. rangiferina*; and 0.03-1.38 µg/g with an average of 0.49 µg/g (standard deviation = 0.41) in *P. schreberi*. The data available for *C. mitis* are too limited to describe statistically, but the values do fall within the range for *C. rangiferina*.

No pattern of unusual regional Se bioaccumulation was found and no comparative information about the Se content of acid precipitation was available for Ontario.

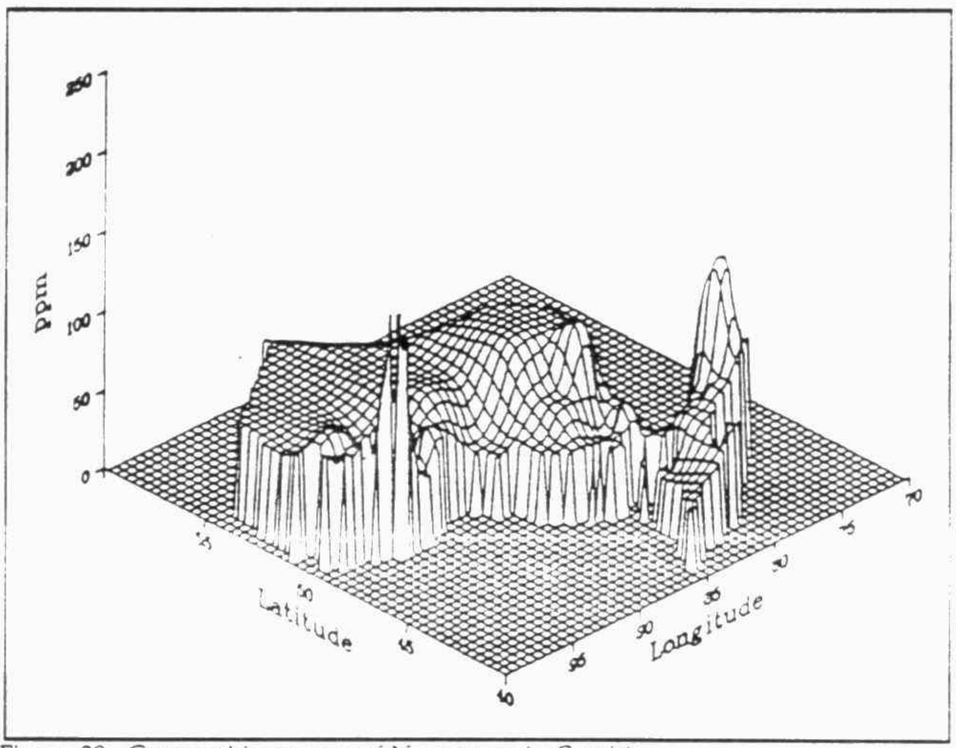


Figure 39. Geographic pattern of Na content in *C. mitis*.

4.4.18. Sodium (Na)

Expected Na content in lichen and moss: 50-600 µg/g (dry weight) (Steinnes, 1977; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Case, 1982).

Observed to date: 23.3-140 µg/g with an average content of 55.05 µg/g (standard deviation = 26.5) in *C. mitis*; 22.3-140 µg/g with an average of 48.2 µg/g (standard deviation = 22.8) in *C. rangiferina*; and 35.7-283 µg/g with an average of 98.0 µg/g (standard deviation = 48.5) in *P. schreberi*.

The geographic pattern of Na content in *C. mitis* is shown in Figure 39. There seems to be a general trend of decreasing Na content as one moves south from the boreal forest region. However, high Na concentrations were found in SE and W Ontario at a couple of sites. These high values may be associated with local soil conditions. The Na content of *C. mitis* and *C. rangiferina* were somewhat

similar (Figure 40). The Na contents of *C. mitis* and *P. schreberi* were not found to be significantly correlated (Figure 41).

The pattern of Na content in *C. mitis* showed little similarity with the pattern of annual concentration of deposition of Na in precipitation (Kirk, 1983; Chan *et al.*, 1984).

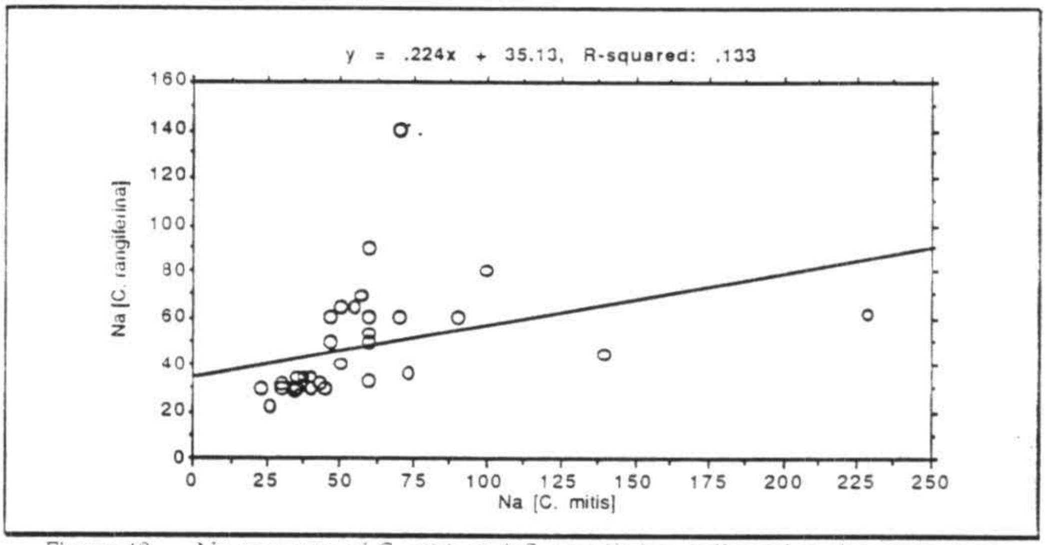


Figure 40. Na contents of *C. mitis* and *C. rangiferina* collected at the same sites.

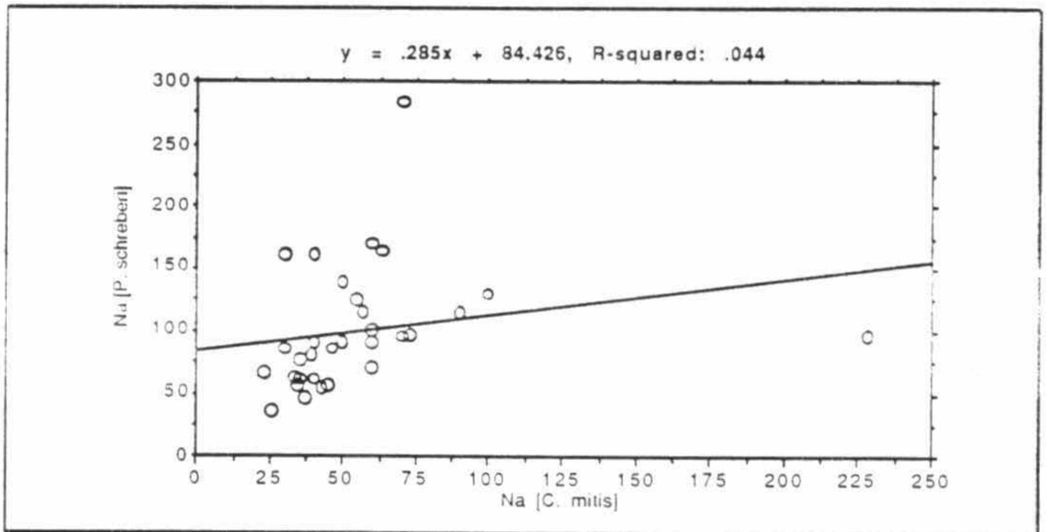


Figure 41. Na contents of *C. mitis* and *P. schreberi* collected at the same sites.

4.4.19. Sulphur (S)

Sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) are the most common contaminant compounds affecting vegetation, soils, and soil microflora. The problems associated with these compounds are well documented in industrial regions all over the world (Overrein, 1977). The effects of sulphur on vegetation and soil in Canada have been reviewed (Rennie and Halstead, 1977). In addition, the impact of sulphur compounds on vegetation and soils has been the subject of many workshops and symposia (e.g., Sandhu and Nyborg, 1977; Sandhu *et al.*, 1982).

Sulphur is essential for normal plant and animal life and is present in all vital tissues. The mobility of sulphur in the biosphere is high since the oxides of sulphur are very soluble in water. However, when compared with other major nutrient elements, knowledge of the dynamics of

sulphur and its nutritional role in agriculture and forest growth is limited (Rennie and Halstead, 1977).

The direct and indirect effects of SO_2 depend upon such factors as species tolerance, concentration, frequency and duration of exposure, soil moisture, and humidity (MacDonald and Klemm, 1973). Intraspecies differences can also occur in response to factors such as age, growth stage, etc. SO_2 is a genotoxic gas which has co-carcinogenic and premutagenic properties. When inhaled with polycylic organic compounds such as benzo(a)pyrene or benzo(k)fluoranthene, SO_2 causes a carcinogenic effect greater than that obtained with benzopyrene alone. These co-carcinogenic and premutagenic properties stem from the ready formation of mutagenic sulphite. Lichens and mosses accumulate sulphur in the presence of SO_2 and thus provide a means of monitoring the long-term presence of this compound.

Expected S content in lichen and moss: 0.012-0.10% (dry weight) (Nieboer *et al.*, 1978; Krouse & Case, 1981, 1983; Case & Krouse, 1980; Case, 1982).

Observed to date: 0.02-0.4% with an average content of 0.05% (standard deviation = 0.06) in *C. mitis*; 0.02-0.1% with an average of 0.04% (standard deviation = 0.02) in *C. rangiferina*; and 0.05-0.17% with an average of 0.09% (standard deviation = 0.03) in *P. schreberi*. Reported sulphur contents of lichens and mosses are very similar to those reported for northern Canada (Nieboer *et al.*, 1978).

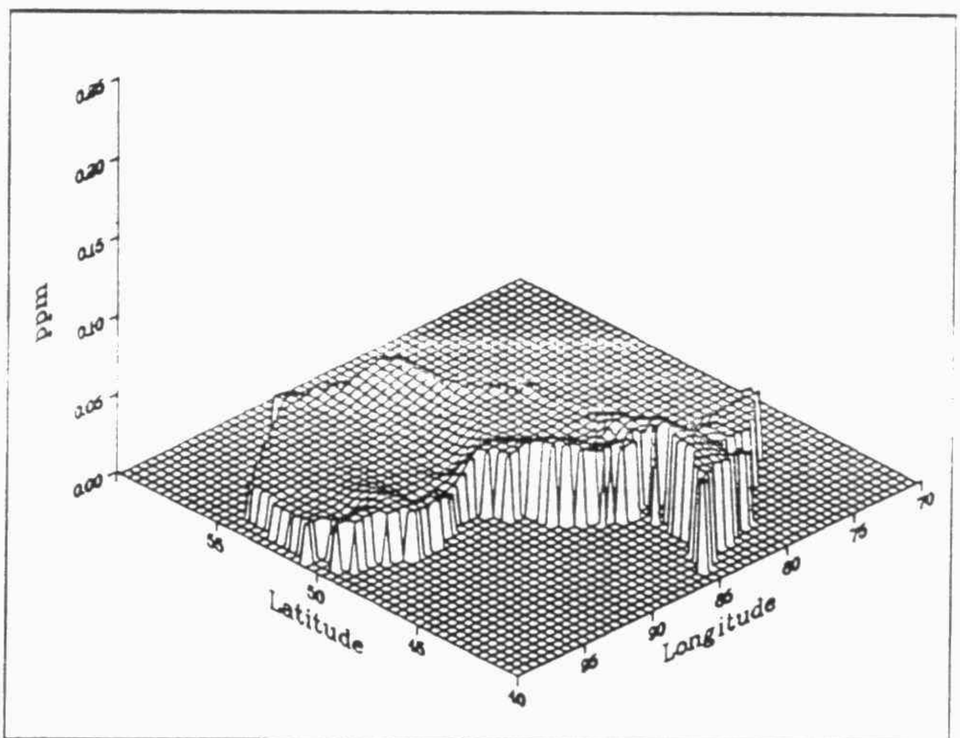


Figure 42. Geographic pattern of S content in *C. mitis*.

The geographic pattern of sulphur content in *C. mitis* is shown in Figure 42. Similar patterns of sulphur concentration exist for *C. rangiferina* and *P. schreberi*, although this is not reflected in their respective correlation coefficients. The patterns of average annual sulphur concentration and deposition of SO_4^{++} (Kirk, 1983; Chan *et al.*, 1984) are very similar to that of sulphur in *C. mitis* samples. The sulphur contents of *C. rangiferina* and *P. schreberi* showed some similarity with that of *C. mitis* (Figures 43 and 44). The correlation may have been better if a more sensitive method had been available for the determination of sulphur content of the lichen and moss samples.

There is a negative north to south gradient of sulphur content with highest levels of sulphur occurring in the C. *mitis* samples from the Dorset region. Insufficient material was available for analysis from extreme southern Ontario due the general paucity of lichens and mosses in that region.

In C. *mitis* and precipitation the highest levels of sulphur were found in southern Ontario. Around Sudbury, high SO_4^{++} contents in precipitation were not reflected in the C. *mitis* sulphur content. This may be the result of missing data due to paucity of C. *mitis* in the immediate vicinity of Sudbury. This is reinforced by the fact that a sample of *Stereocaulon tomentosum*, which has a habitat similar to that of C. *mitis*, had a sulphur content of 0.09%; one of the highest values measured for ground-dwelling lichens in this study.

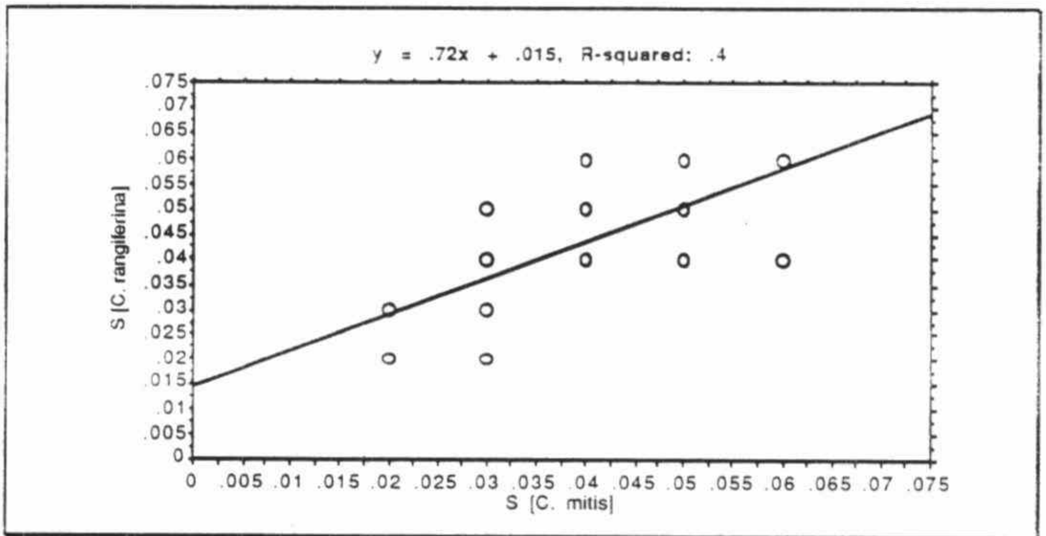


Figure 43. S contents of C. *mitis* and C. *rangiferina* collected at the same sites.

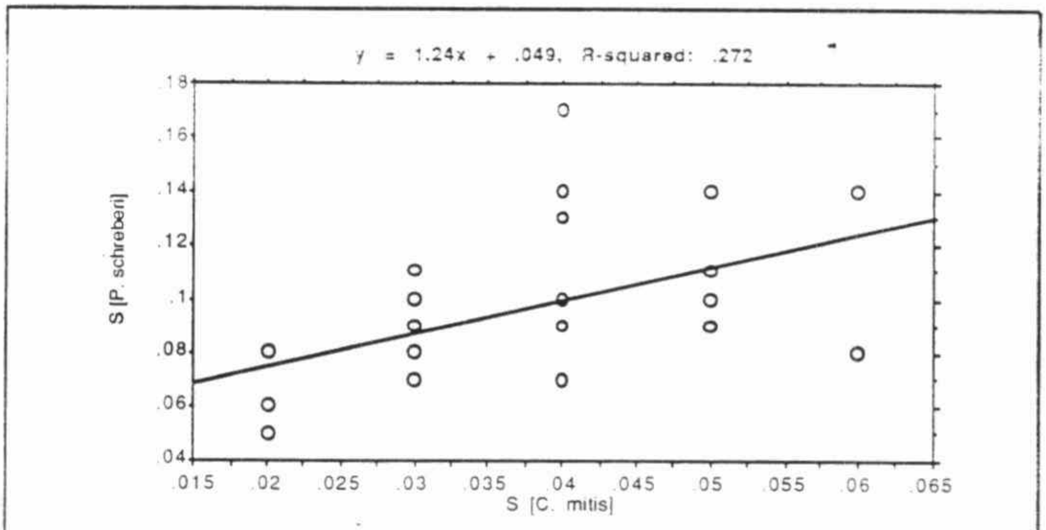


Figure 44. S contents of C. *mitis* and P. *schreberi* collected at the same sites.

4.4.20. Titanium (Ti)

Ti has a low inherent toxicity and low carcinogenicity.

Expected Ti content in lichen and moss: 6-150 µg/g (dry weight) (Laaksovirta & Olkkonen, 1976; Nieboer *et al.*, 1978; Case, 1982).

Observed to date: 45.0-520.0 µg/g with an average content of 104.7 µg/g (standard deviation = 97.4) in *C. mitis*; 40.5-360.0 µg/g with an average of 85.4 µg/g (standard deviation = 75.8) in *C. rangiferina*; and 27.7-1120.0 µg/g with an average of 150.4 µg/g (standard deviation = 194.6) in *P. schreberi*. The geographic pattern of Ti content in *C. mitis* is shown in Figure 45.

Very high levels of Ti were found in *C. mitis* from SE Ontario. The origin of this Ti is not obvious but may be related to soil chemistry, manufacturing, regional agricultural practices and/or urbanization. Elevated levels of Ti were also found in areas of mining activity near Sudbury and Dorion. Ti levels throughout northern Ontario appear to be uniformly low.

Ti contents of *C. mitis* and *C. rangiferina* were correlated (Figure 46). The Ti contents of *P. schreberi* and *C. mitis* were less similar (Figure 47).

No comparative information was available about the Ti content of precipitation in Ontario.

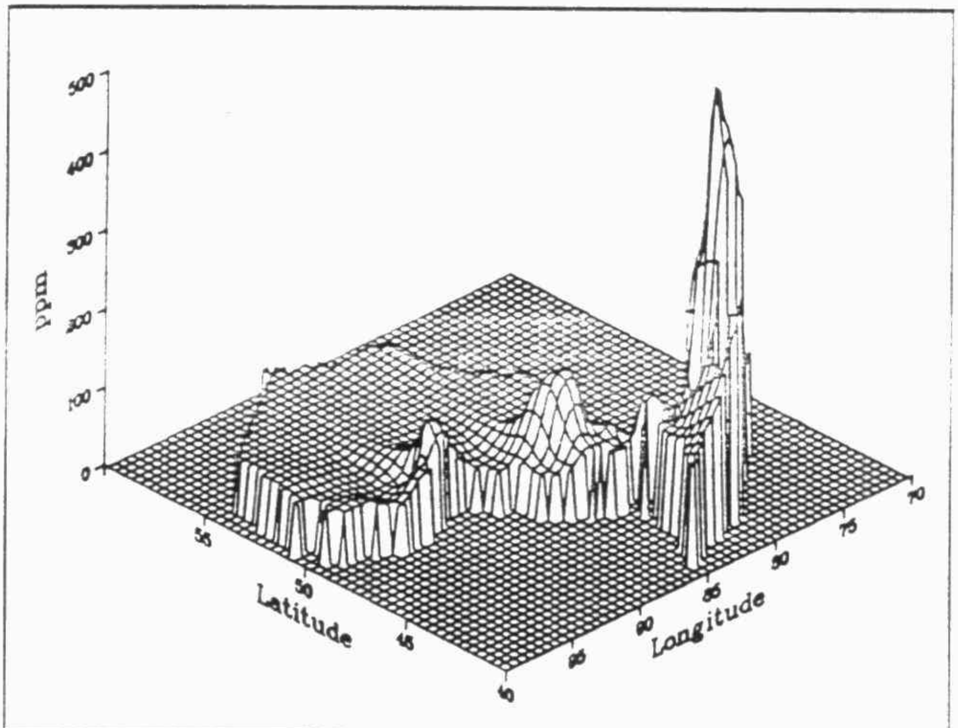


Figure 45. Geographic pattern of Ti content in *C. mitis*.

4.4.21. Vanadium (V)

V is reported to be carcinogenic (Sawicki, 1978), but has a low degree of inherent toxicity (CCL, 1978). Local effects in animals include acute and chronic problems with the respiratory system. Metabolic effects include interference with biosynthesis of cystine and cholesterol, depression and stimulation of phospholipid synthesis and, at higher concentrations, inhibition of serotonin oxidation.

V occurs only sparsely in the natural environment (Nygård and Harju, 1983) and is an excellent indicator element for pollution dispersal and deposition studies because quite high concentrations are emitted by industrial activities. Fortunately, inhaled and ingested V compounds are poorly absorbed.

Expected V content in lichen and moss: 0-10 µg/g (dry weight) (Tuominen & Jaakkola, 1973; Steinnes, 1977; Nieboer *et al.*, 1978; Case, 1982).

Observed to date: 0.9-7.9 µg/g with an average content of 2.25 µg/g (standard deviation = 1.75) in *C. mitis*; 0.66-7.0 µg/g with an average of 1.8 µg/g (standard deviation = 1.37) in *C. rangiferina;* and 1.5-9.7 µg/g with an average of 3.46 µg/g (standard deviation = 1.92) in *P. schreberi*.

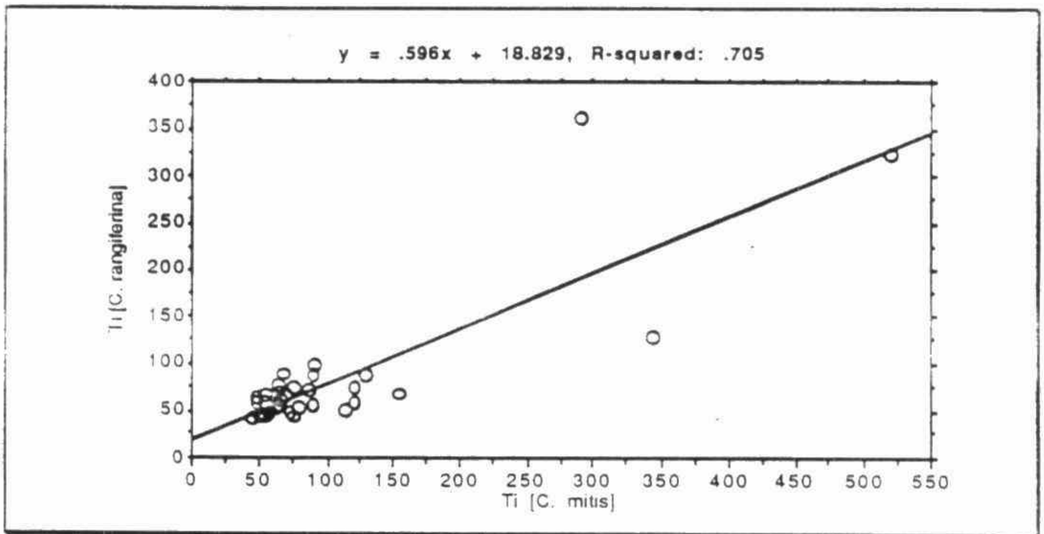


Figure 46. Ti contents of *C. mitis* and *C. rangiferina* collected at the same sites.

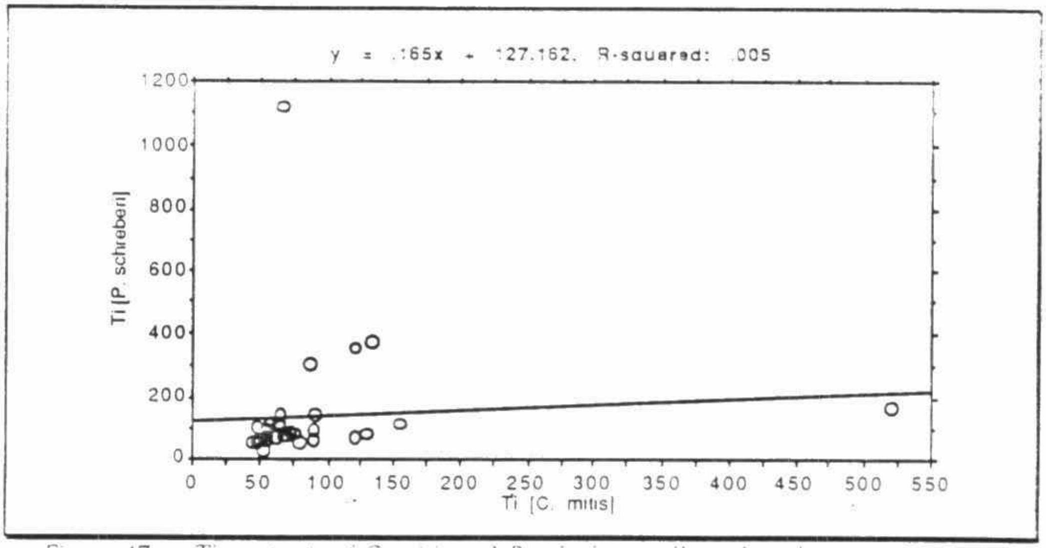


Figure 47. Ti contents of *C. mitis* and *P. schreberi* collected at the same sites.

The geographic pattern of V content in *C. mitis* is shown in Figure 48. With the exception of N Ontario, the V contents of *C. mitis* are fairly uniform throughout the province. In S Ontario elevated V levels were detected in *C. mitis* collected on rock outcrops. The lower V levels in SW Ontario are based on a lack of data points. V contents of *C. rangiferina* were similar to those of *C. mitis* (Figure 49) while *P. schreberi* showed little similarity to *C. mitis* (Figure 50).

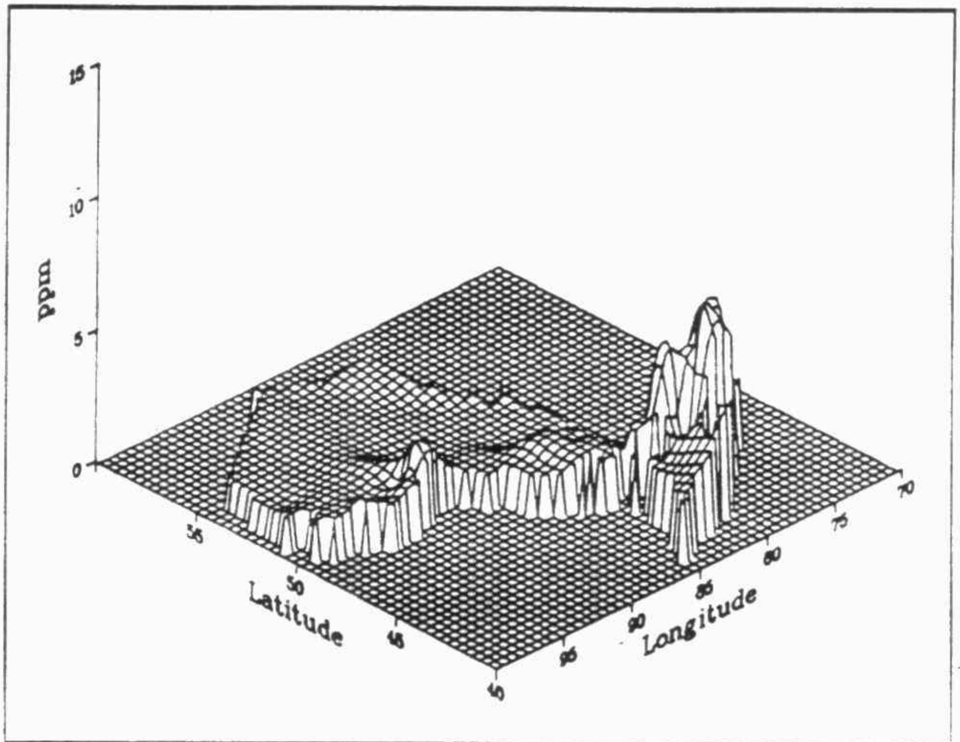


Figure 48. Geographic pattern of V content in *C. mitis*.

No contour maps of the average annual concentration of V in precipitation or deposition due to precipitation were available in Chan *et al.* (1984) because the content of this element in precipitation samples was usually at the detection limit. This suggests that the cryptogams get a very small proportion of their V from precipitation. Rather, the principal source of their V is likely particulate matter which quickly drops out of the air.

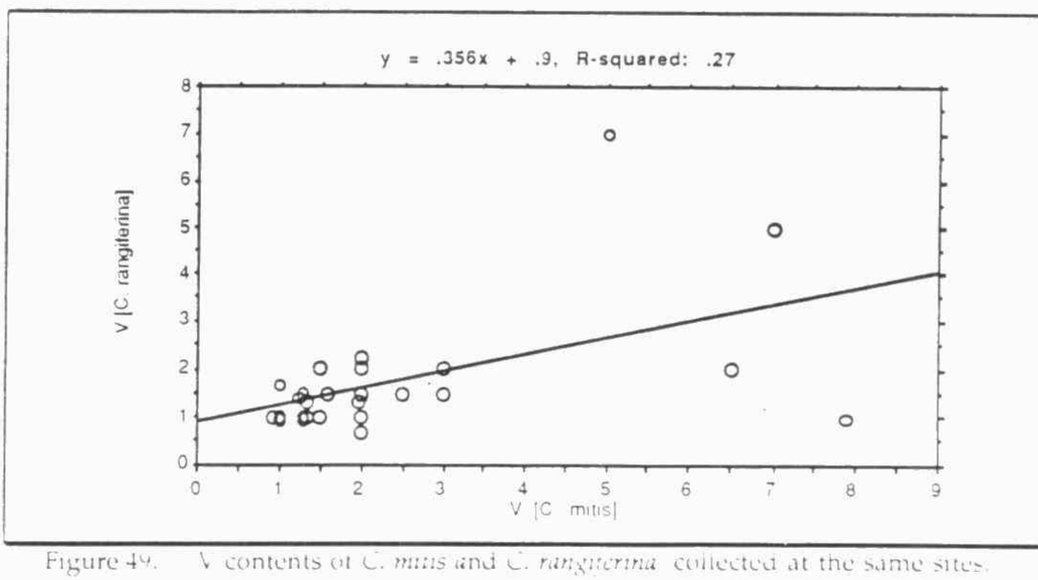


Figure 49. V contents of *C. mitis* and *C. rangiferina* collected at the same sites.

4.4.22. Zinc (Zn)

Zn is reported to be highly carcinogenic (Sawicki, 1978) but has a low degree of toxicity (CGL, 1978).

> Expected Zn content in lichen and moss: 20-500 µg/g (dry weight) (Steinnes, 1977; Nieboer *et al.*, 1978; Bosserman and Hagner, 1981; Martin & Coughtrey, 1982; Case, 1982).

> Observed to date: 10.5-121.0 µg/g with an average content of 26.2 µg/g (standard deviation = 22.2) in *C. mitis*; 13.0-136.0 µg/g with an average of 26.0 µg/g (standard deviation = 20.4) in *C. rangiferina*; and 22.0-131.4 µg/g with an average of 44.2 µg/g (standard deviation = 19.8) in *P. schreberi*.

The geographic pattern of Zn content in *C. mitis* is shown in Figure 51. The Zn content of *C. mitis* throughout northern Ontario is fairly uniform. However, regions of elevated Zn content are evident in the Plastic Lake–Wilberforce area, in the Sudbury region, and in the White River area. The apparently low level of Zn in *C. mitis* of SW Ontario is an artifact due to a lack of data.

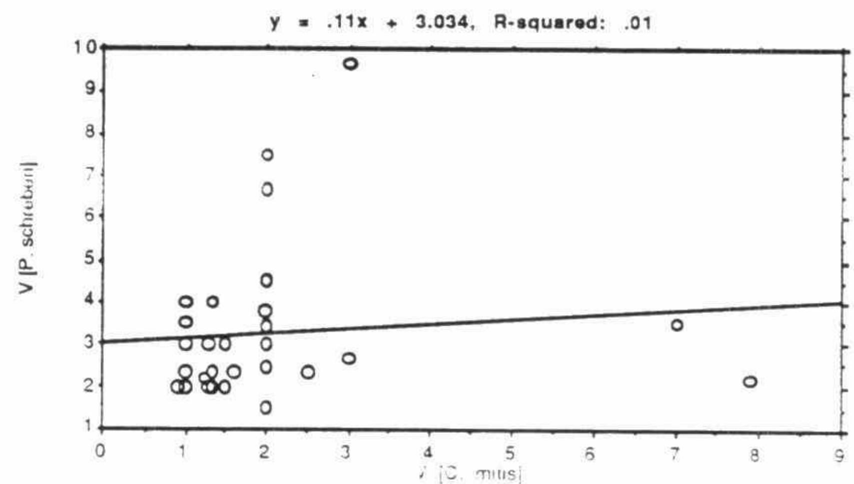


Figure 50. V contents of *C. mitis* and *P. schreberi* collected at the same sites.

The Zn contents of *C. mitis* and *C. rangiferina* are related (Figure 52). Zn content of *P. schreberi* is not significantly correlated with that of *C. mitis* or *C. rangiferina*.

The regional pattern of Zn, average annual Zn concentration, and annual Zn deposition due to precipitation (Kirk, 1983; Chan *et al.*, 1984) show little similarity to levels of Zn measured in *C. mitis*.

4.4.23. Toxicity Potential

A literature survey was conducted to determine the toxic potential of each element measured because there exists a real potential for adverse effects not only for vegetation, but also for the health of animals and humans, from long-term exposure to some elements which were found to be accumulating in the lichens and mosses at some sites in the study region (MNR, 1987; Glooschenko *et al.*, 1988). The ratings given above are pertinent to the effects of the element by itself and not in the presence of other elements. No attempt has been made to rate the toxicological potential for plants or animals of element combinations.

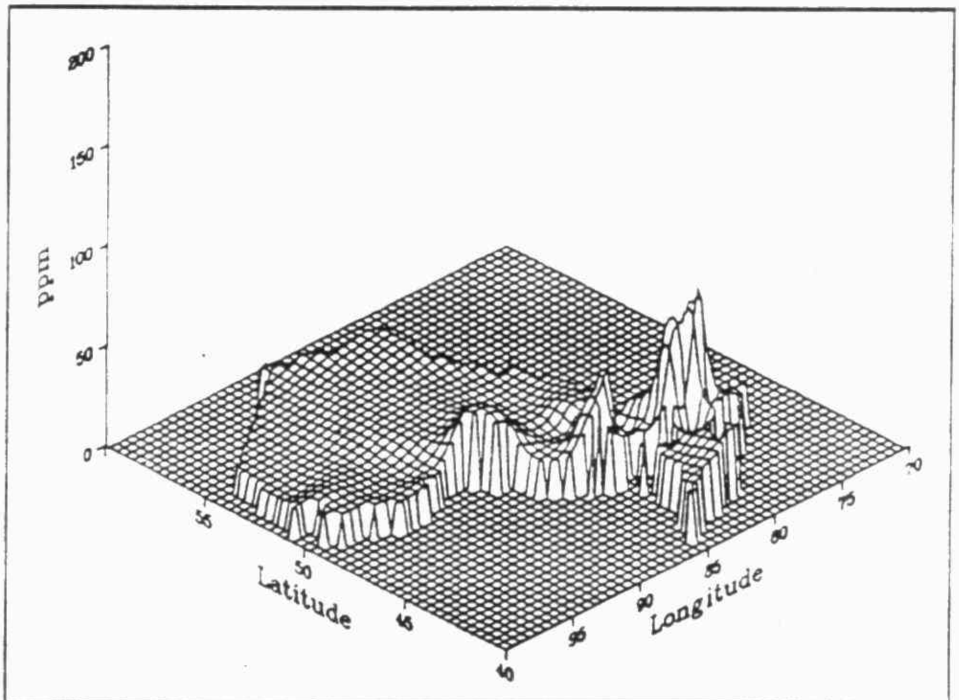


Figure 51. Geographic pattern of Zn content in *C. mitis*.

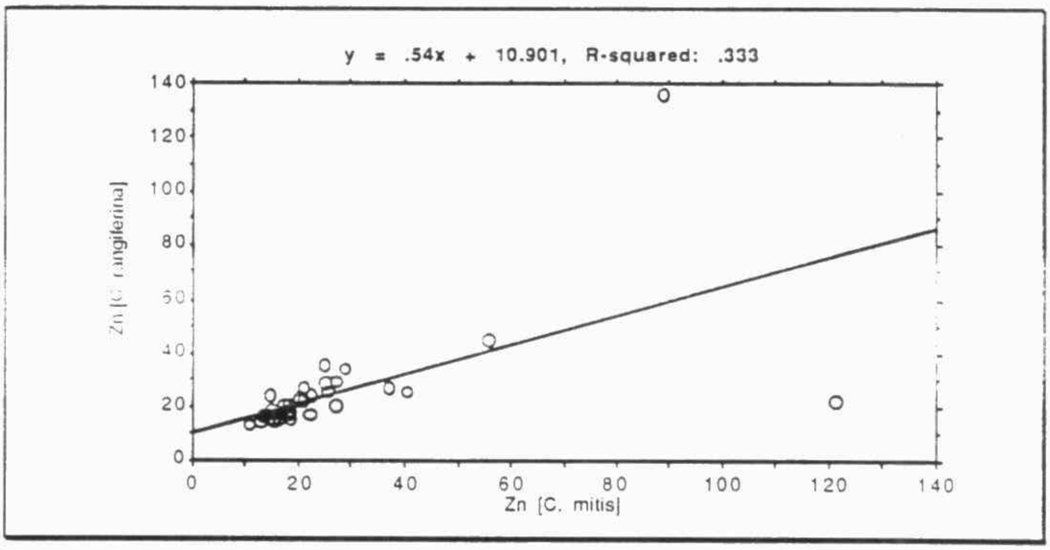


Figure 52. Zn contents in *C. rangiferina* and *C. mitis* collected at the same sites.

4.5. Discussion

4.5.1. Elemental Bioaccumulation in Lichens and Mosses

Since one of the goals of this study was to assess whether lichen and moss biomonitors could be used to monitor acid precipitation, it was important to demonstrate that the elemental content of more than one species showed similar patterns of accumulation. Correlation coefficients were calculated to provide a measure of agreement between the elemental contents of three common and

widespread species; *Cladina mitis*, *Cladina rangiferina* and *Pleurozium schreberi*. The coefficients are presented in the Results (Section 4.4).

In general, the elemental contents of *C. mitis* and *C. rangiferina* were similar. Examination of the scatter plots of element concentration shows that the contents of Al, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Ni, Na, S, Ti, V, and Zn in the two species appear to be related. However, only in the case of Al, Cu, Fe, Ni, and Ti was the relationship statistically significant.

Examination of element concentration scatter plots of *C. mitis* versus *P. schreberi* from the same locations reveals that their contents of Al, Ca, Cu, Fe, Pb, Mg, Ni, N, and S are somewhat similar. However, there was considerable variation. Only Cu and Ni were significantly correlated.

Some information about the origin of the elements measured in the lichen and moss samples can be obtained by examining the correlation between elements within species to determine which groups 'travel' together. Tables 5, 6 and 7 show the correlation between elements in *C. mitis* , *C. rangiferina* and *P. schreberi*, respectively.

One group of elements which seem to travel together are, Al, Fe, Mg, Ti and V. These elements are significantly correlated in all species studied. It is not surprising then that they have very similar concentration patterns in Ontario. The relatively high levels of Al, Fe, Mg, Ti and V found in SE Ontario, and the relatively low levels found in the Sudbury and Dorion regions suggest that windblown dust, rather than smelting and mining, is the principal source of these elements in the vegetation samples.

Cu and Ni concentrations in the region around Sudbury are elevated far above the levels measured in samples from N and NW Ontario. These two elements appear to be accumulating to very high levels in the environment. A certain proportion of the input of these elements would be from fall-out from Sudbury. However, some may be due to dissolved ions in run-off water derived from exposed surficial ore deposits. Both of these elements are known to be biologically active.

Pb levels are, in general, well correlated with those of Cd and S. However, S is not significantly correlated with Cd. This suggests that at least two main sources for Pb. These elements may be associated with the combustion of coal.

4.5.2. Comparison of Elemental Bioaccumulation in *Cladina mitis* and Cumulative Acid Precipitation Chemistry

In the past an almost anecdotal folklore had developed by which it was 'understood' that lichens were excellent bioindicators of air pollution because they were extremely sensitive to the phytotoxic effects of SO_2 (and compounds derived from SO_2). They were also good biomonitors because they could accumulate high levels of metals without succumbing to their toxic effects. It was thought that the elemental contents of the lichens reflected a long-term average pollutant concentration (Ferry *et al.*, 1973). This belief existed in spite of the fact that instrumental monitoring had shown that the concept of 'long-term pollution concentration' existed only as a mathematical concept, and that studies of ecological systems had demonstrated that ecosystems are in a continual state of fluctuation as the component organisms responded to stimuli.

Levels of Fe or Ni in cumulative precipitation samples from APIOS monitoring stations explain little of the variability in Fe or Ni in *C. mitis* from the same or nearby sites. Examination of the maxima, minima and standard deviations for the metal concentrations in cumulative precipitation samples (Kirk, 1983; Chan *et al.*, 1984) reveals extreme variability in elemental content that must exist between samples.

Metal content of *C. mitis* shows no relationship with average pH values of cumulative precipitation samples. In the future, it might be more meaningful to compare element concentrations in bioaccumulators with the weighted average of "effective $[H^+]$" or $[H^+]$ - $[HCO_3^-]$

as it may give a better representation of the actual acidity available (Lau, 1982).

Figure 53 is an isopach 3D image based on the difference between the standard normalized average annual average ambient S content of cumulative precipitation samples (Kirk, 1983) and the standard normalized S content measurement of *Cladina mitis*. It illustrates that the levels of S in the lichens are higher than would be expected on the basis of contributions from precipitation alone. It should not be viewed as a display of an amount of S, rather, isopach figures are illustrations of relative agreement or disagreement. If there was no agreement there would be no relief. If there was nearly perfect agreement there would be a flat-topped plateau.

Figure 54 is a 3D image based on the products of standard normalized cumulative precipitation SO_4 values (Kirk, 1983) and S content in *C. mitis*. It illustrates that in extreme southern and NW regions of Ontario, average cumulative precipitation sample S content is a good predictor of S content in lichens. However, in central Ontario agreement drops sharply. This is interpreted as being indicative of the important contribution of SO_2 from the Sudbury area to the S content of the lichens. Perhaps not surprisingly, the same relationship exists between precipitation pH and S in *C. mitis*.

Figure 55 is a isopach 3D image based on the difference between the standard normalized average annual average ambient Pb content of cumulative precipitation samples (Kirk, 1983) and the Pb content of *C. mitis*. The isopach figure illustrates that the levels of Pb in the lichens are higher than would be expected on the basis of contribution from precipitation alone. In Figure 56, however, which is a 3D image based on the products of standard normalized cumulative precipitation chemistry (Kirk, 1983) and Pb content of *C. mitis*, it can be seen that in extreme southern Ontario and parts of northern Ontario, average annual Pb content of cumulative precipitation is a good predictor of Pb contents of *C. mitis*.

Figure 57 is a 3D image illustrating the isopach between the standard normalized average annual average ambient Fe content of cumulative precipitation samples (Kirk, 1983) and the Fe content of *C. mitis*. The isopach figure illustrates that the levels of Fe in the lichens throughout most of Ontario are higher than would be expected on the basis of contribution from precipitation alone. In Figure 58, however, which is a 3D image based on the products of standard normalized cumulative precipitation chemistry (Kirk, 1983) and Fe content measurements, it appears that average annual Fe content of cumulative precipitation is a significant contributor to the Fe contents of *C. mitis* in the same region. Al, Mg, Ti and V showed similar patterns.

Figures 59 is an isopleth contour map based on the product of standard normalized cumulative precipitation Ni values and Ni in *C. mitis*. There is good agreement between precipitation and *C. mitis* values in the Sudbury area. Since Ni was in the precipitation and the lichen, it would appear that Ni washed out of the air is a major source of Ni for the lichen. The contribution of Ni to the lichen from exposed rock in the area is not known.

An overview of map comparison techniques is presented in Appendix C.

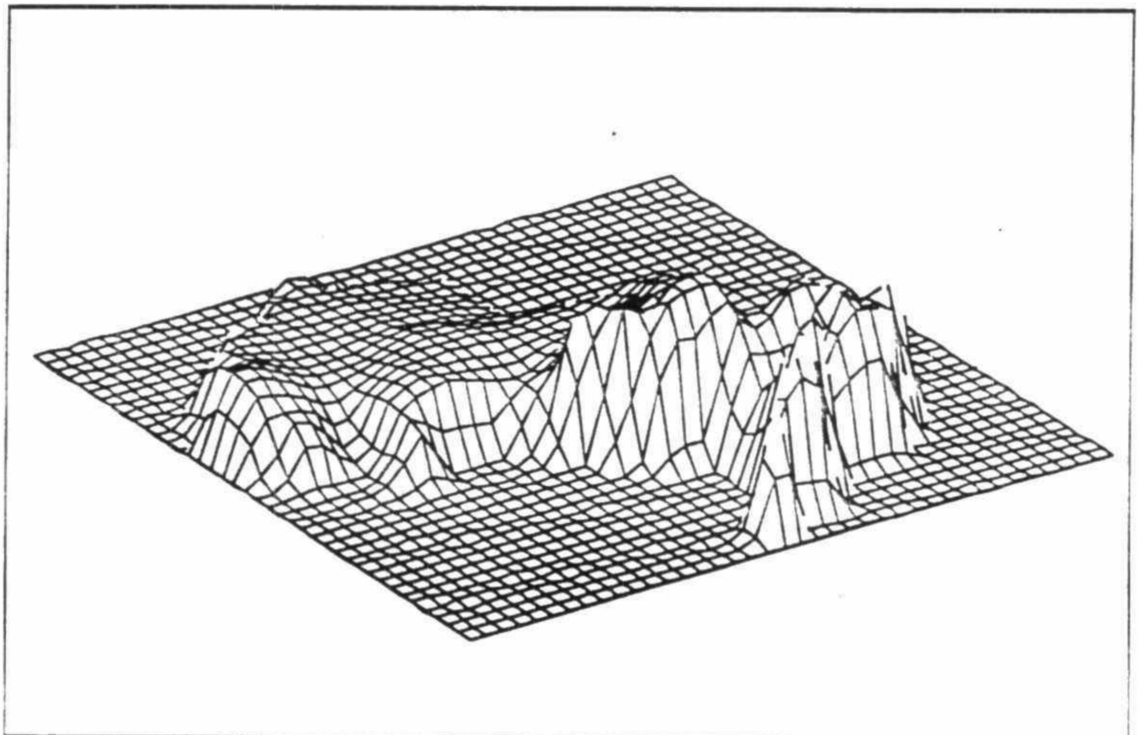


Figure 53. Three dimensional isopach representation of the difference between the S concentration of C. *mitis* and cumulative precipitation samples

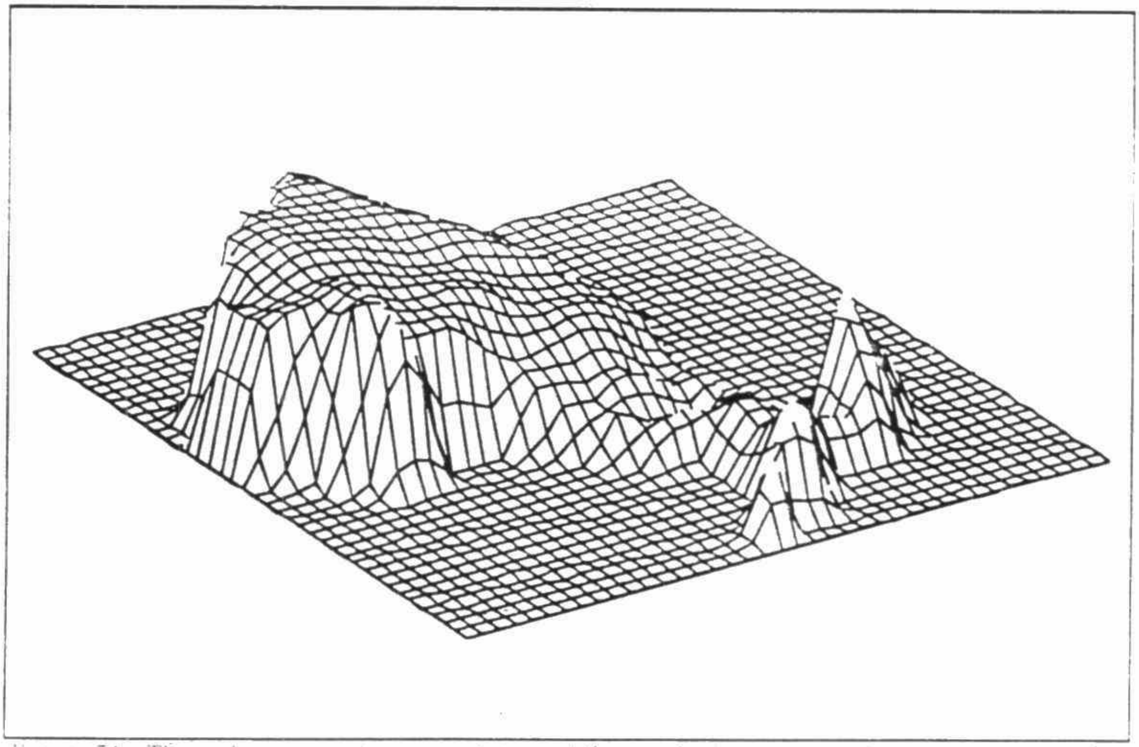


Figure 54. Three dimensional representation of the product matrix for S concentration in C. *mitis* and cumulative precipitation samples.

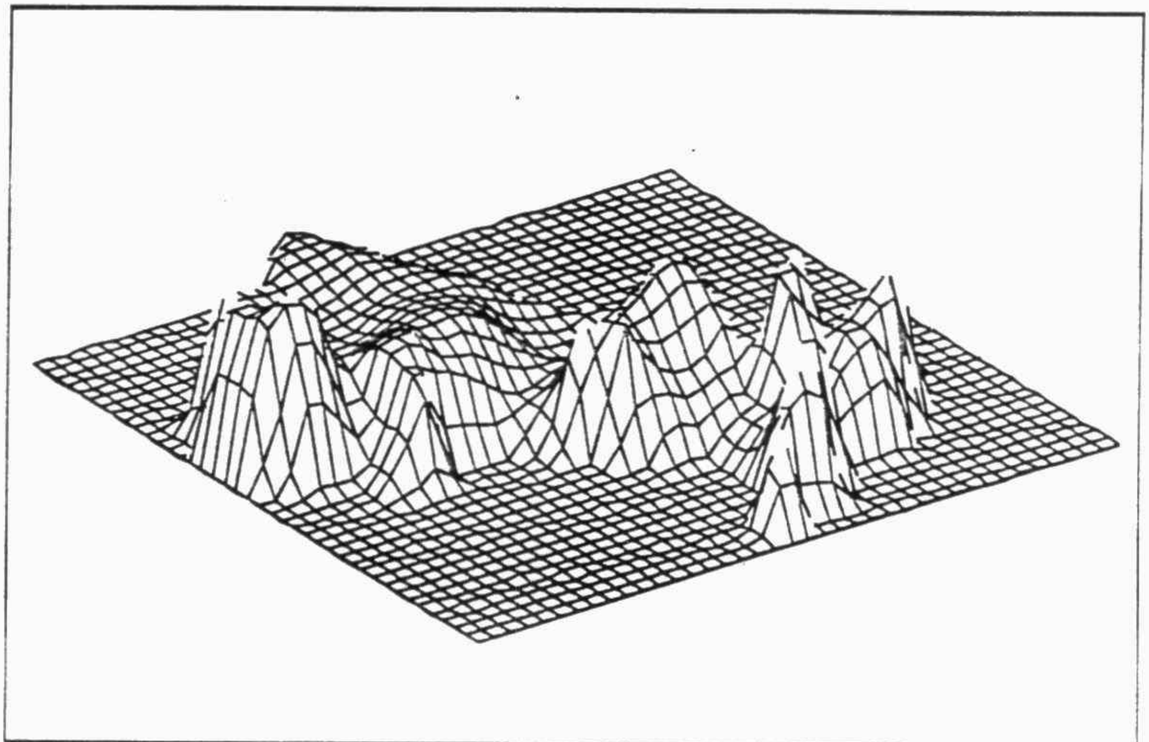


Figure 55. Three dimensional isopach representation of the difference between Pb concentration of *C. mitis* and cumulative precipitation samples.

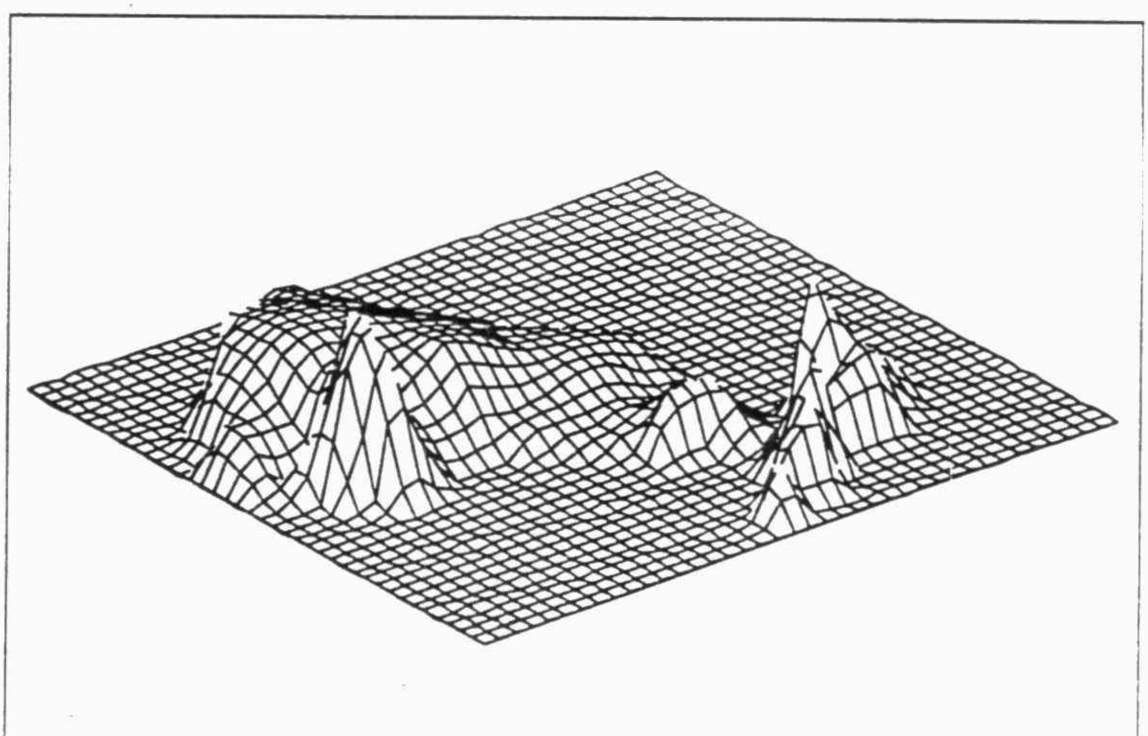


Figure 56. Three dimensional representation of the product matrix for Pb concentration in *C. mitis* and cumulative precipitation samples.

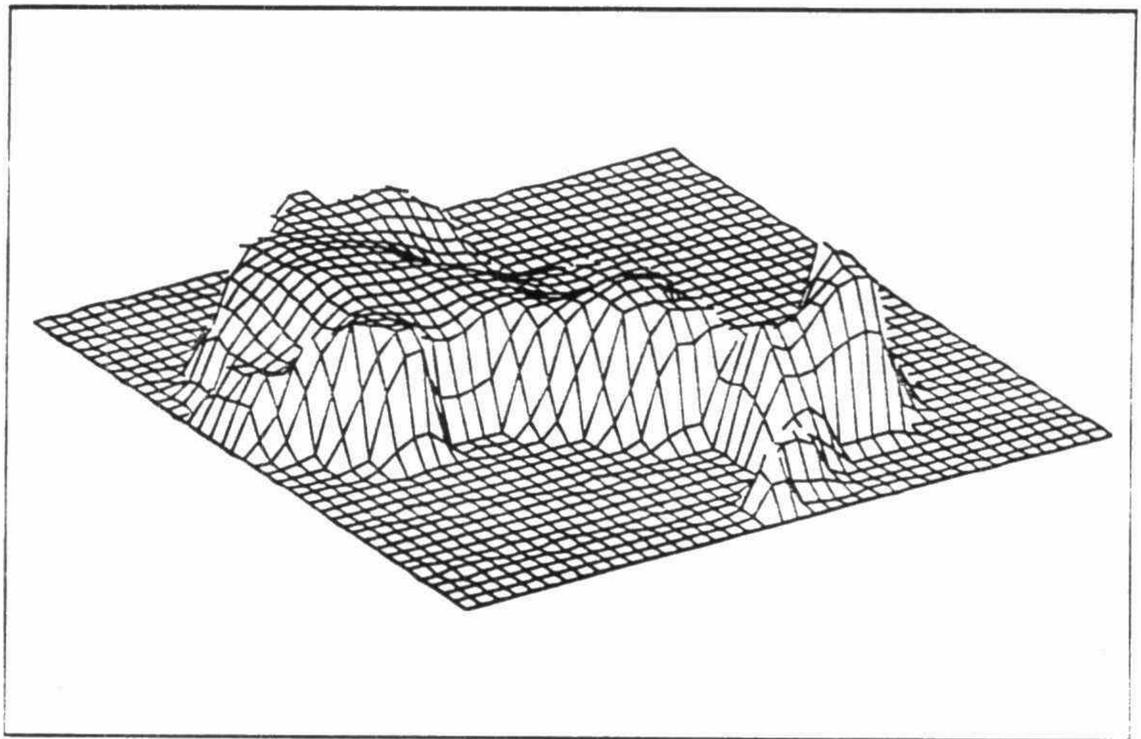


Figure 57. Three dimensional isopach representation of the difference between Fe concentration of *C. mitis* and cumulative precipitation samples.

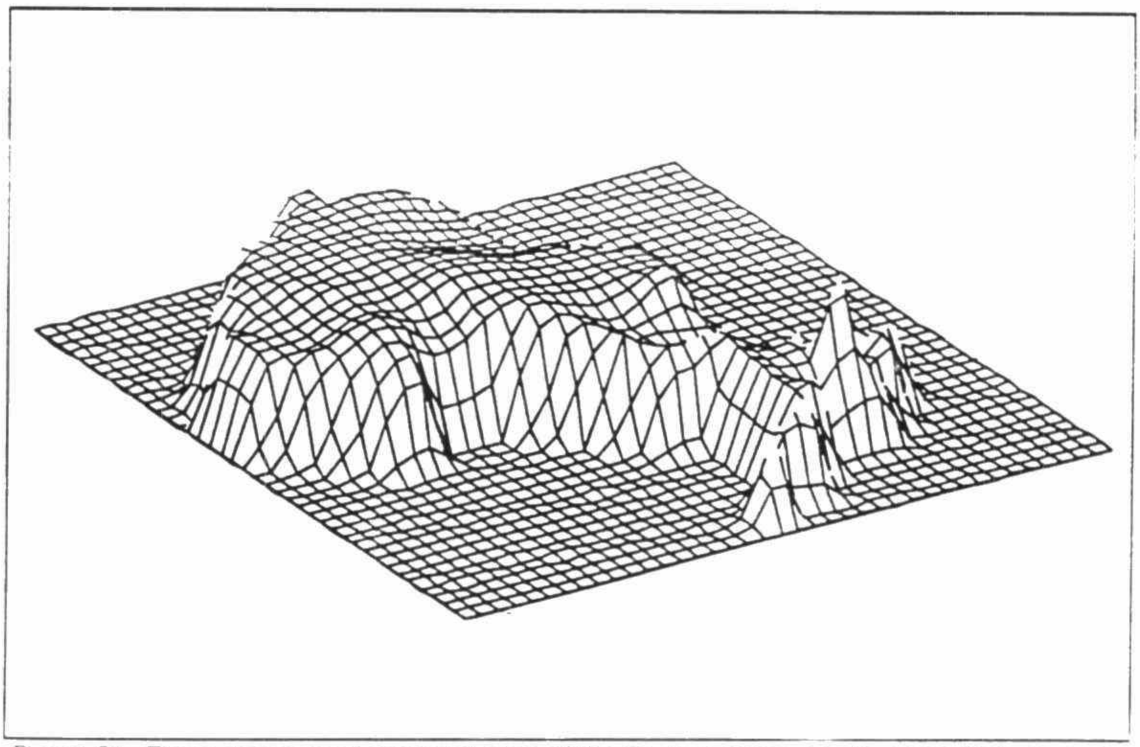


Figure 58. Three dimensional representation of the product matrix for Fe concentration in *C. mitis* and cumulative precipitation samples.

Figure 59. A comparison of the Ni content of precipitation with that of *C. mitis*.

4.6. Conclusions

The major factors affecting the content of bioactive elements in lichens and mosses in Ontario appear to be gaseous and particulate emissions from point sources, wind-blown dust, and elements derived from subsurface minerals dissolved in surface run-off water.

Contribution of contaminants from precipitation does affect the element contents of lichens and mosses but it is not usually the most important contributing factor. Precipitation chemistry is a good predictor of some elements in lichens and mosses in some regions of the province. Sulphate, nitrate, and lead in precipitation appear to be major contributing factors to the accumulation of S, N and Pb in *C. mitis*. The levels of most elements in lichens and mosses are higher than would be expected on the basis of contribution from precipitation alone. The geographic patterns of many element concentrations suggest that they are related to both precipitation chemistry, local sources of air pollution such as urban environments, smelters, power plants, and other emission sources of trace elements, and probably mineral ores in rock. Availability of metals from rock will be influenced by the pH of precipitation.

Comparison of elemental contents in *Cladina mitis* with those of *C. rangiferina* revealed a high correlation between the two species. The elemental contents of *C. mitis* and *Pleurozium schreberi* were less similar.

Very significant correlations were found consistently for certain pairs of elements in all species. Some elements, such as Cu and Ni, or Al, Fe, Mg, Ti and V, apparently travel together.

5. FOLLOWING THE ELEMENTAL CONTENT IN *CLADINA* OVER TIME

5.1. Introduction

Seasonal variations of bioactive element content has been demonstrated for many species of plants. This variation can be related to seasonal changes in plant physiology and fluctuations in the availability of compounds in the environment. For example, deciduous tree leaves typically show maximum metal concentrations just prior to leaf-fall (Martin and Coughtrey, 1982). Lichens also show seasonal variation in physiology (e.g., Farrar, 1973) therefore their elemental content may also show seasonal variation.

5.2. Purpose

The purpose of the present study was to determine if the elemental composition of lichen and moss samples from the BGC sites fluctuated during the year, or whether it was constant (or at least within the range of natural variability).

5.3. Methods

Replicate samples of *Cladina mitis*, *C. rangiferina* and *Pleurozium schreberi* were collected three times yearly during the growing season at the BGC sites (Plastic Lake, Hawkeye Lake and High Falls) according to the methods described in Section 4. The samples were submitted to the Ontario Ministry of the Environment laboratory in Toronto and analyzed to determine their contents of 19 elements (Al, Ca, Cd, Cl, Cr, Cu, Fe, K, Mg, Mn, N, Na, Ni, P, Pb, S, Ti, V, and Zn).

5.4. Results

The results of the analyses are indicated by a "T"in Appendix A. Most measurements of Cl were at or below the detection limit of the method used and not discussed further. Figures 60 - 77 show the elemental contents of *C. mitis*, *C. rangiferina*, and *P. schreberi* collected at Hawkeye Lake, which was the most pristine site. The elemental contents of *C. mitis* samples collected at all three BGC sites are summarized graphically in Figures 78 - 95. Standard error bars for the samples are shown.

5.5. Discussion

The environment at Hawkeye Lake was relatively pristine and the natural input of elements is not strongly altered by input of large amounts of contaminants. The concentrations of most elements in *C. mitis*, *C. rangiferina* and *P. schreberi* showed relatively minor fluctuations throughout the study period (Figures 60 - 77). The elemental contents of the two *Cladina* species were relatively constant over time. With the exceptions of Mg and Mn the elemental contents of the two *Cladina* species were very similar for samples collected on the same date and generally tracked each other throughout the period of the study.

In most cases the elemental concentrations in *Pleurozium schreberi* were higher than those measured in the *Cladina* species sampled at the same time and place. The fluctuation in content were also greater although they generally tracked those of the *Cladina* samples. The exceptions were the concentrations of N and P which were much lower in the *Pleurozium* samples collected in the first week of October, 1983 and May of 1984. However, the concentrations were up to their previous higher levels again by late June of 1984 , where they remained even up to the first week of October when the last samples were taken. Neither of the *Cladina* species showed this fluctuation in N and P content. This is most likely due to physiological differences between the moss and lichen living at the same site. It would appear that during the winter months the nutritive value of the moss and lichens as a source of N and P would be very similar.

In the case of Al, Cr, Mn, and Ni there is some indication of an increase in concentration samples collected at Hawkeye Lake over the duration of the study.

Based on the comparison of the analysis results for all species sampled at Hawkeye Lake, *Cladina mitis* was selected as a representative species for an examination of differences in elemental content in samples collected at the three BGC study sites. Elemental concentrations in *C. mitis* at the 3 BGC study sites are shown in Figures 78 - 95. These figures show that Al, Cu, Fe, K, N, Ni, Pb, S, Ti, V and Zn in *C. mitis* collected at High Falls had decreasing concentrations during the period from early May 1983 to mid-May 1984, after which the concentration started increasing over time. This phenomenon was not observed at either of the other BGC study sites. The concentration decrease and subsequent increase observed at High Falls may be associated with a strike at Inco in Sudbury during the month of June in 1982, followed by a 10 month scheduled shut-down at Inco. This resulted in almost an entire year during which the Sudbury "Super stack" released virtually no emissions. What appears in the graphs could be explained by a "dilution" effect resulting from the addition of new contaminant free tissue to the lichen thalli at a rate greater than the rate at which the contaminants began to accumulate in the thallus tissue when the smelter started emissions again.

The lichens apparently began producing contaminant-free new tissue almost immediately resulting in a net decrease in "whole thallus" concentration. Although contaminants would have started appearing again in the environment again in early April, 1983, when Inco started-up the "Super stack", the production of contaminant free tissue resulted in a decrease in the effective whole thallus elemental content. One year later the rate of, metal accumulation had overtaken the production of new tissue and the resulting "whole thallus" concentration began increasing.

An alternative explanation could be that when the "Super stack" began operations again in April of 1983, there was a decrease in local (fugitive) emissions which was detectable within 1 or 2 months as a decrease in elemental contents in the lichen. This presupposes the existence of an unknown but substantial local emission source which ceased when the "Super stack" began operations again. No such local emission source is known and such a mechanism cannot account for the increases in elemental content observed starting in May of 1984.

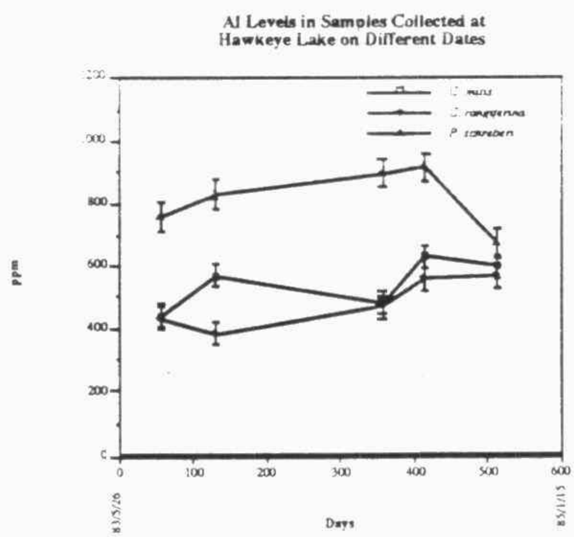


Figure 60. Variation in Al content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

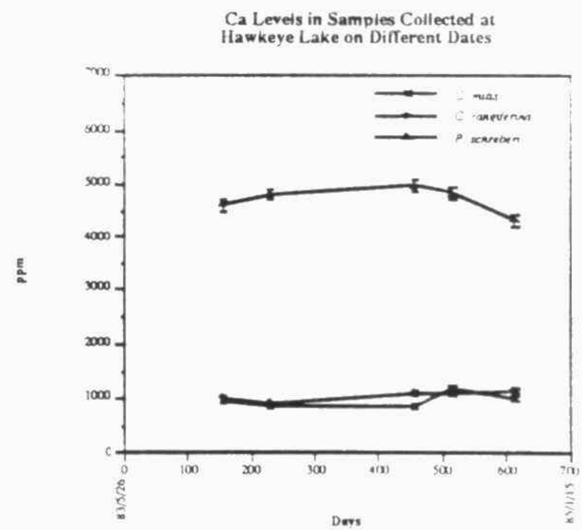


Figure 61. Variation in Ca content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

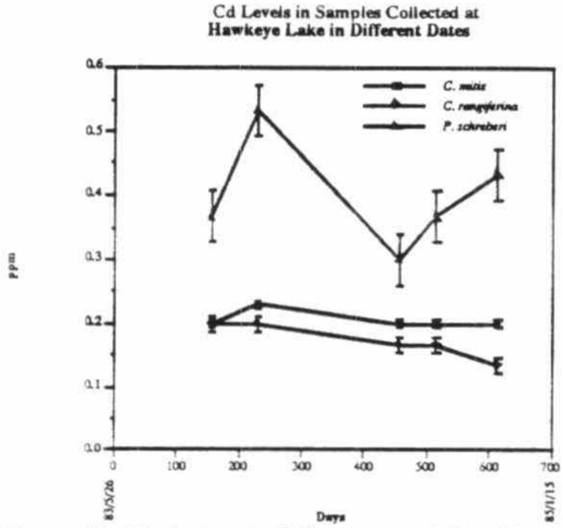


Figure 62. Variation in Cd content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

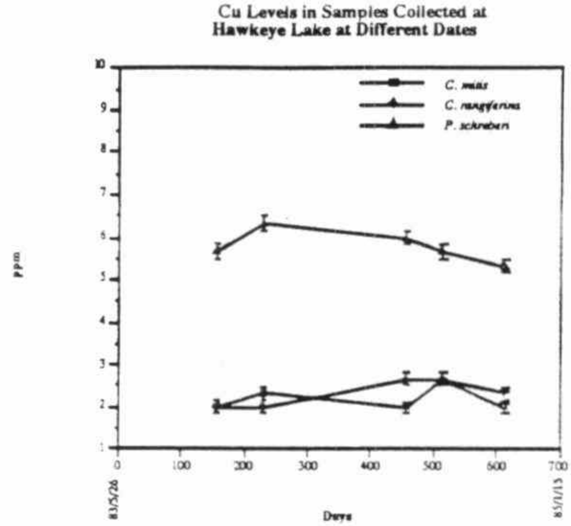


Figure 64. Variation in Cu content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

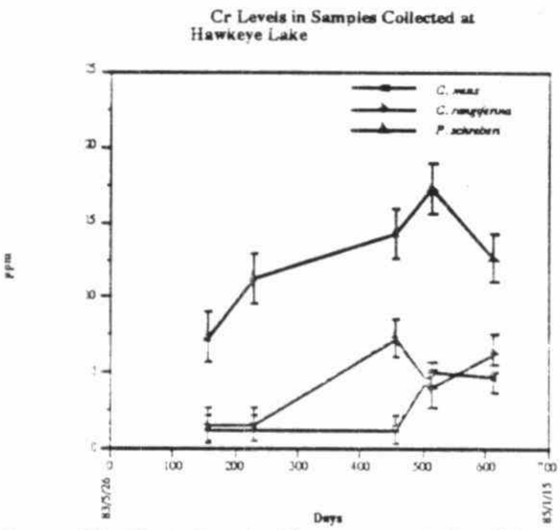


Figure 63. Variation in Cr content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

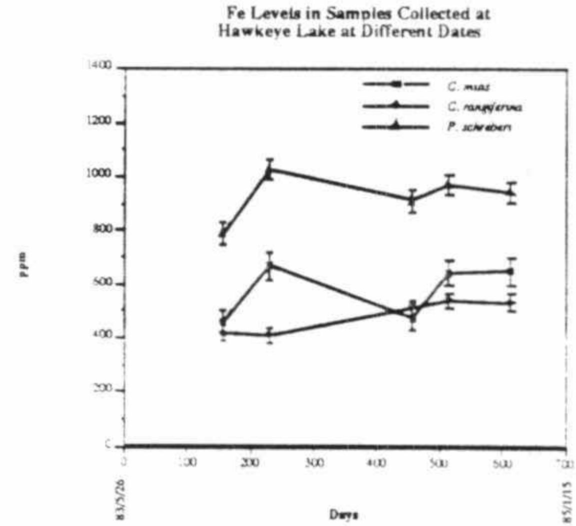


Figure 65 Variation in Fe content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

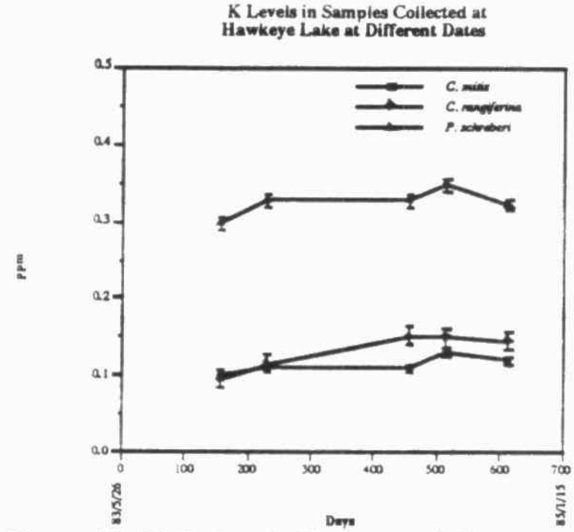


Figure 66. Variation in K content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

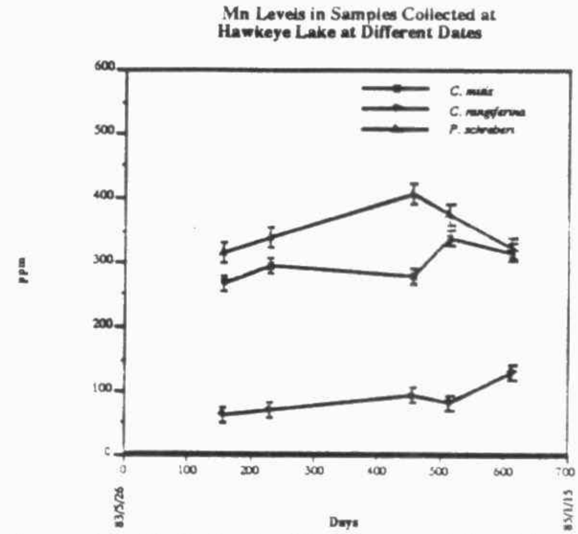


Figure 68. Variation in Mn content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

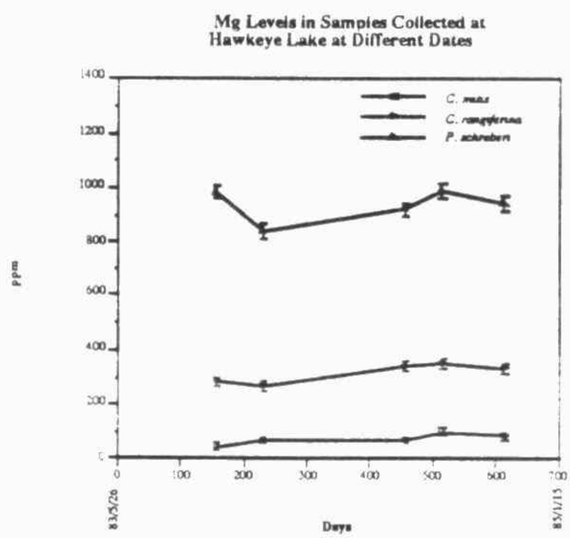


Figure 67. Variation in Mg content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

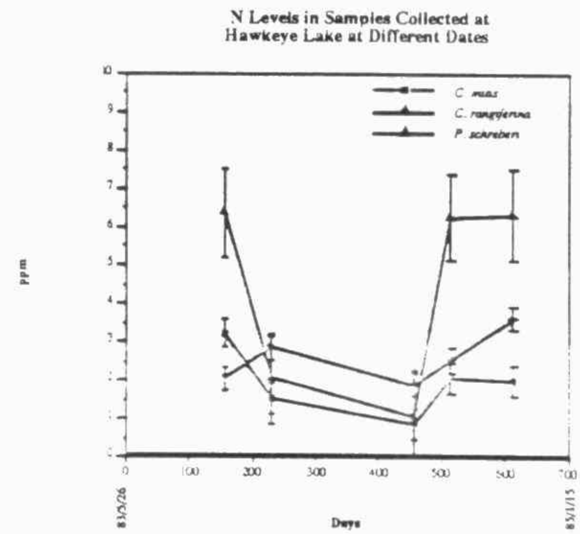


Figure 69. Variation in N content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

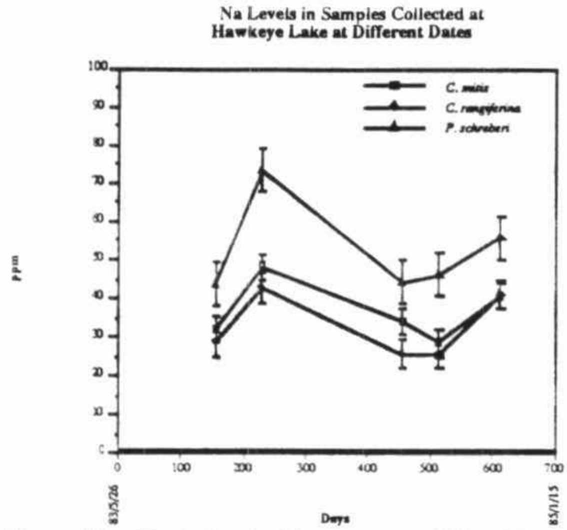


Figure 70. Variation in Na content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

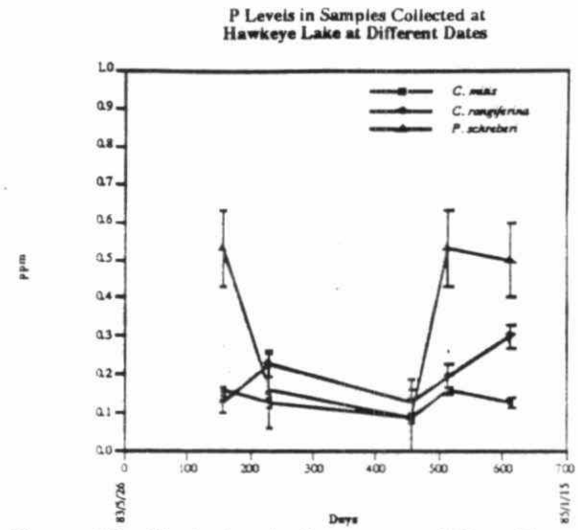


Figure 72. Variation in P content of *C. mitis*. *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

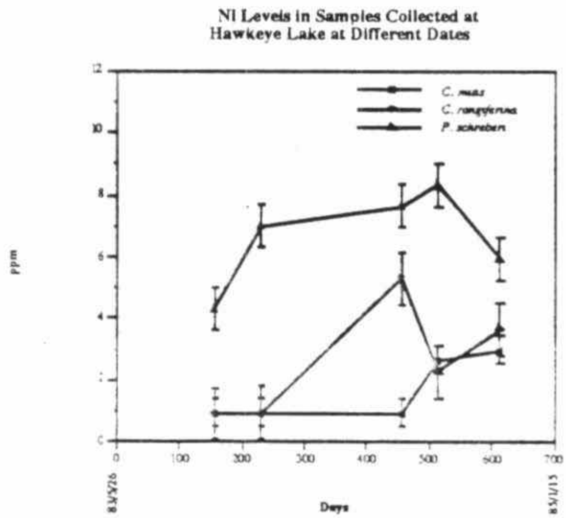


Figure 71. Variation in Ni content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

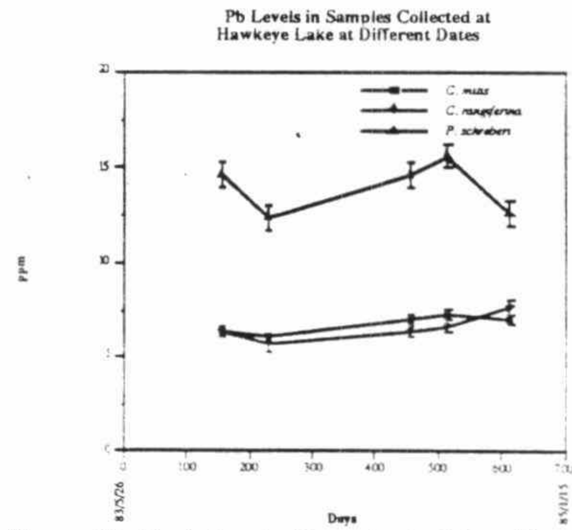


Figure 73. Variation in Pb content of *C. mitis*, *C. rangiferina* and *P. schreberi* at Hawkeye Lake, over time.

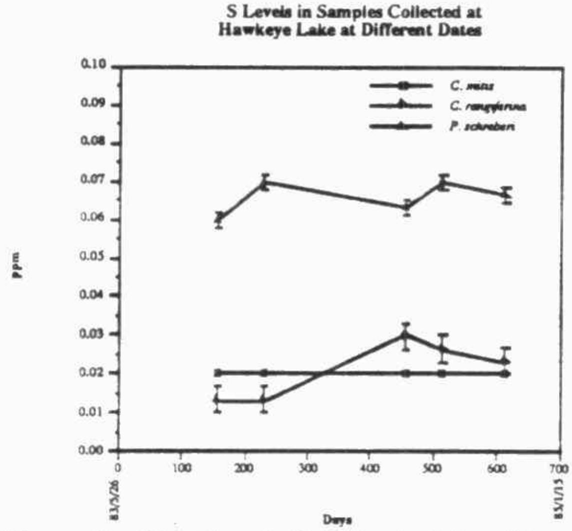


Figure 74. Variation in S content of C. *mitis*, C. *rangiferina* and P. *schreberi* at Hawkeye Lake, over time.

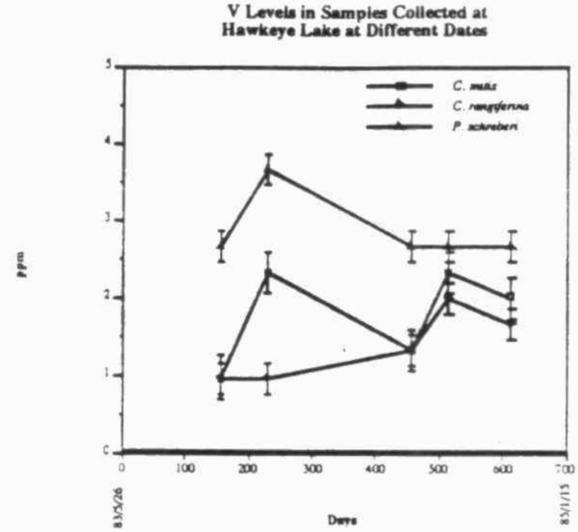


Figure 76. Variation in Cu content of C. *mitis*, C. *rangiferina* and P. *schreberi* at Hawkeye Lake, over time.

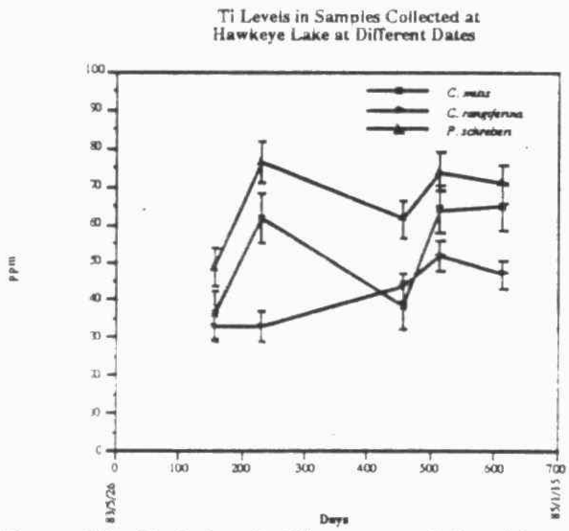


Figure 75. Variation in Ti content of C. *mitis*, C. *rangiferina* and P. *schreberi* at Hawkeye Lake, over time.

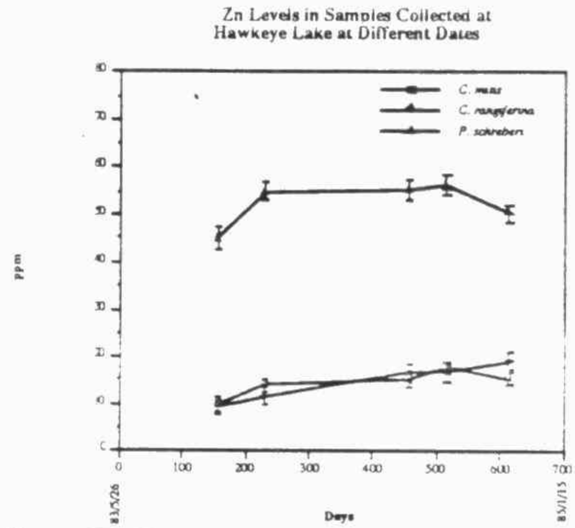


Figure 77. Variation in Zn content of C. *mitis*, C. *rangiferina* and P. *schreberi* at at Hawkeye Lake, over time.

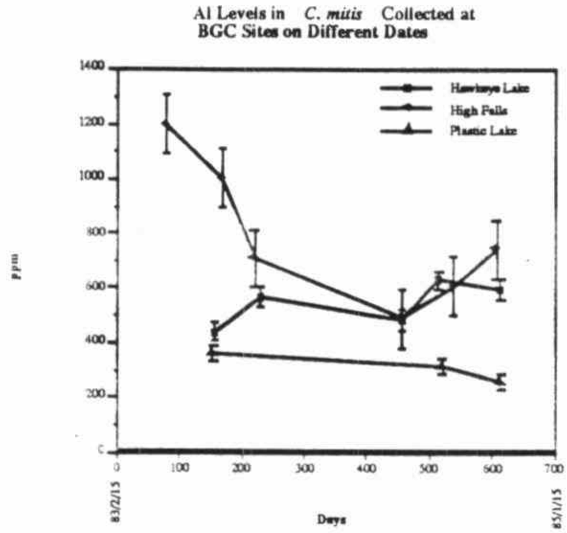


Figure 78. Variation in Al content of *C. mitis* over time.

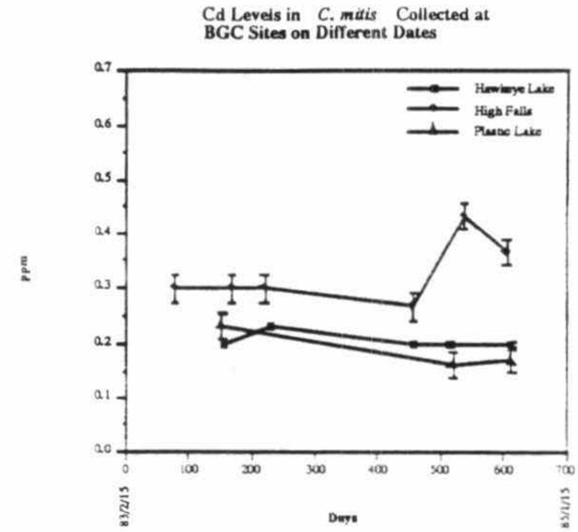


Figure 80. Variation in Cd content of *C. mitis* over time.

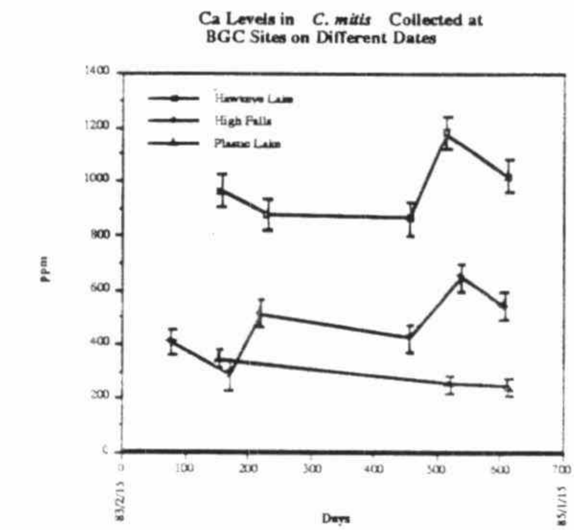


Figure 79. Variation in Ca content of *C. mitis* over time.

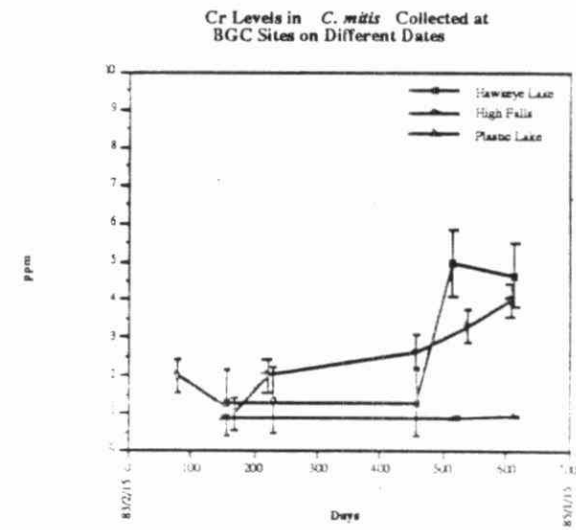


Figure 81. Variation in Cr content of *C. mitis* over time.

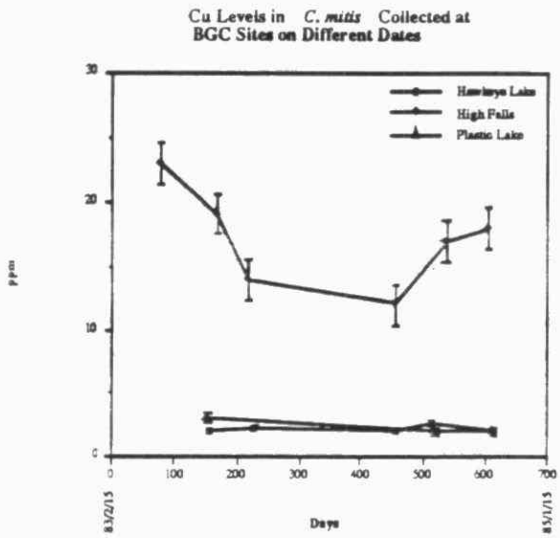


Figure 82. Variation in Cu content of *C. mitis* over time.

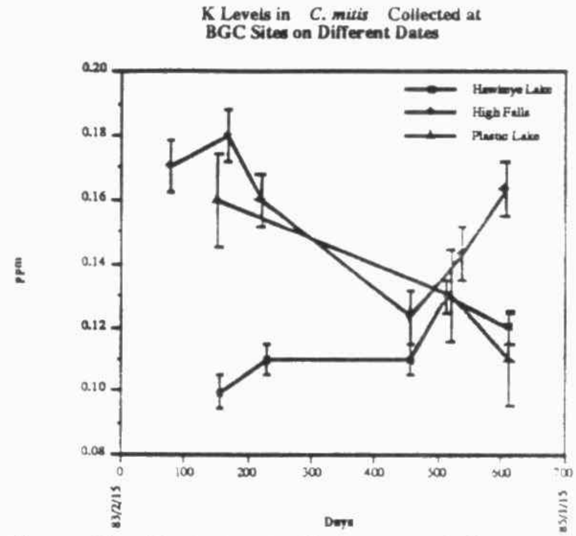


Figure 84. Variation in K content of *C. mitis* over time.

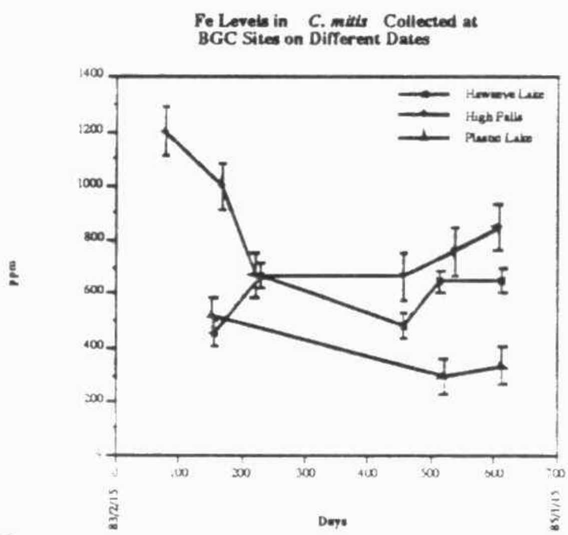


Figure 83. Variation in Fe content of *C. mitis* over time.

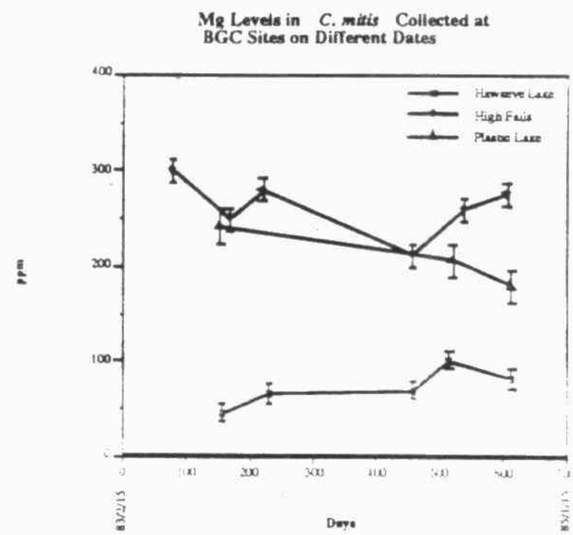


Figure 85. Variation in Mg content of *C. mitis* over time.

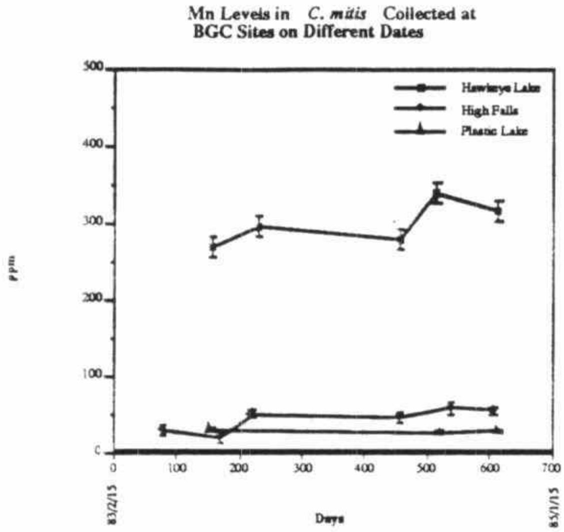


Figure 86. Variation in Mn content of *C. mitis* over time.

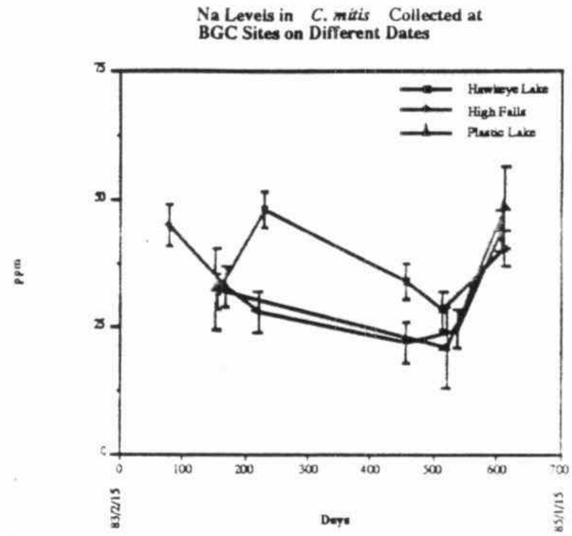


Figure 88. Variation in Na content of *C. mitis* over time.

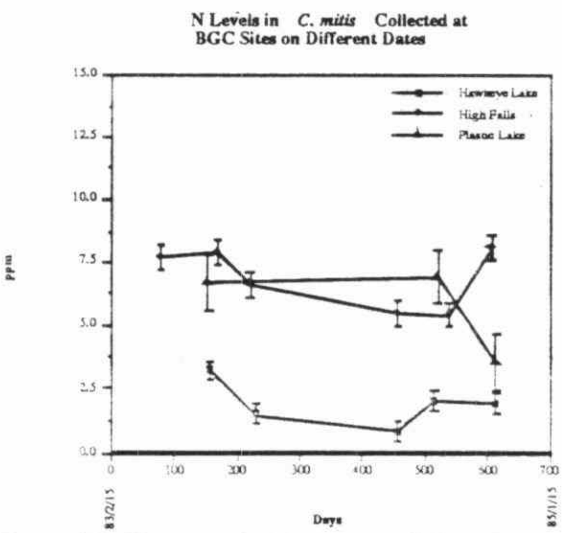


Figure 87. Variation in N content of *C. mitis* over time.

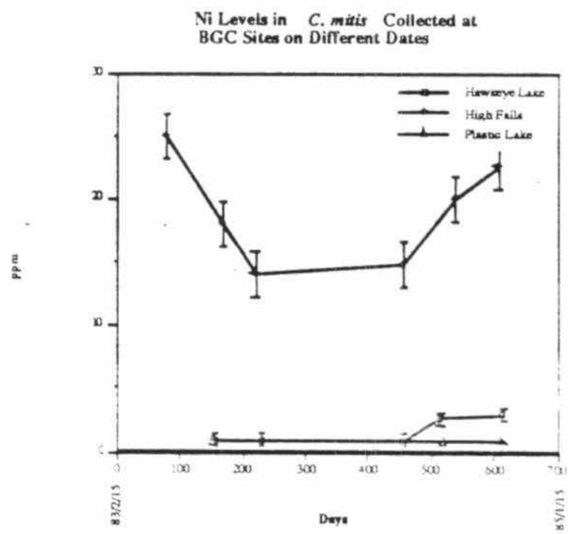


Figure 89. Variation in Ni content of *C. mitis* over time.

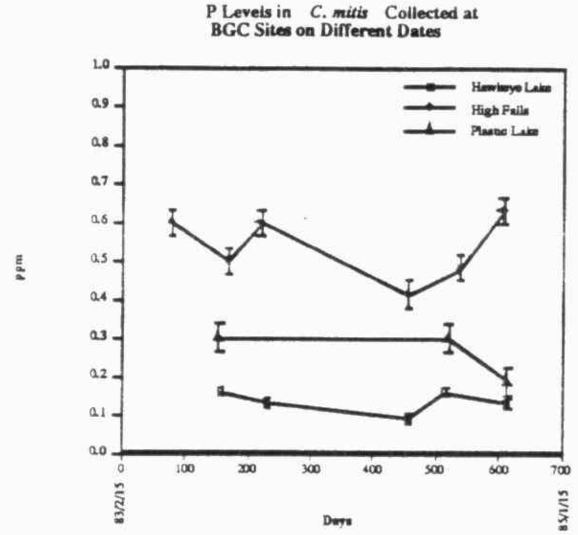


Figure 90. Variation in P content of *C. mitis* over time.

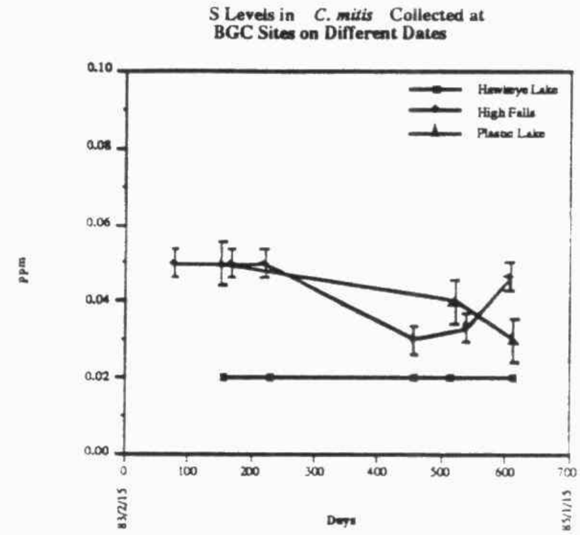


Figure 92. Variation in S content of *C. mitis* over time.

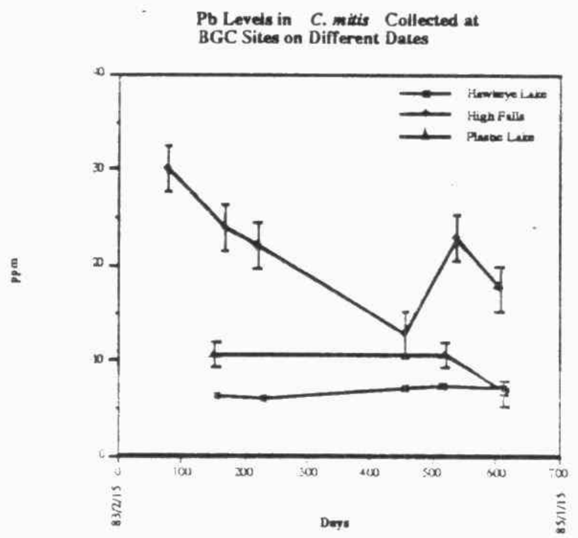


Figure 91. Variation in Pb content of *C. mitis* over time.

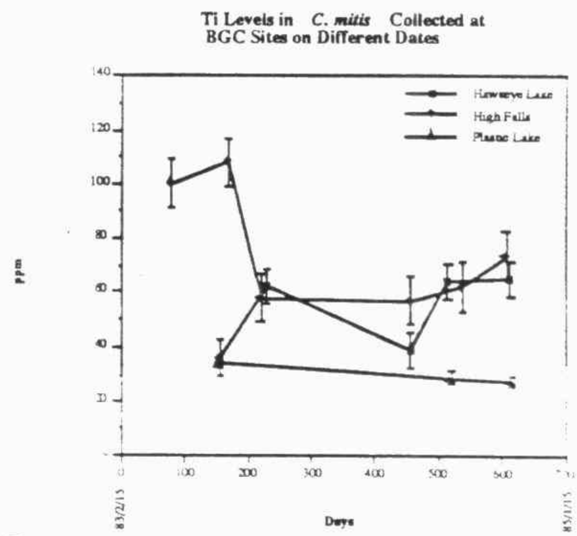


Figure 93. Variation in Ti content of *C. mitis* over time.

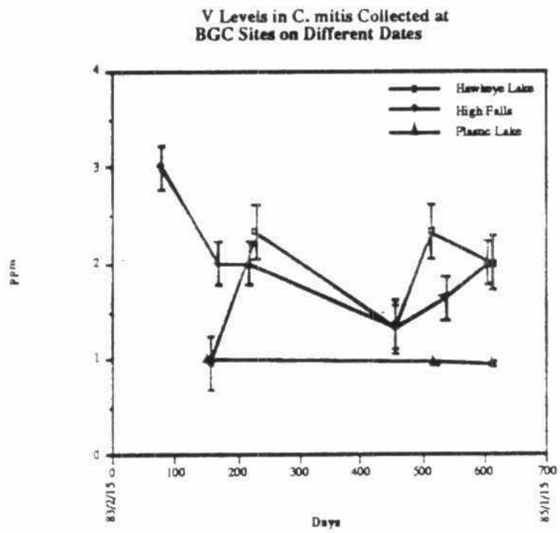


Figure 94. Variation in V content of C. *mitis* over time.

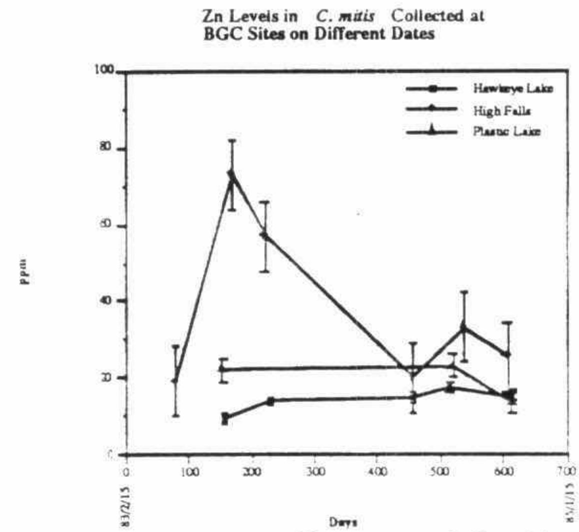


Figure 95. Variation in Zn content of C. *mitis* over time.

5.6. Conclusions

Do cryptogamic species maintain a constant elemental composition throughout the year? The elemental analysis results for replicates of C. *mitis*, C. *rangiferina* and P. *schreberi* collected at the BGC study sites at designated intervals over a three year span demonstrated that the content of many elements was not constant.

Although the elemental measurements of C. *mitis* did not remain constant from season to season (Figures 78 to 95) there was insufficient data to say whether or not the fluctuations were seasonal. However, given that other types of vegetation exhibit seasonal variations, it is still preferable that lichen samples be collected at the same time each year if analysis results from different years are going to be compared.

The elemental contents of Al, Cr, Cu, Mn, Pb, and S in C. *mitis* from the High Falls site near Sudbury were generally the highest and were observed to vary (sometimes greatly) over relative short periods of time. By comparison, the elemental contents of the samples from Plastic Lake and the relatively pristine Hawkeye Lake were much less variable, although the elemental contents were generally higher at Plastic Lake.

The elemental concentrations in C. *mitis* collected at the BGC study sites indicate that the Hawkeye Lake site was the most pristine; that the High Falls site received the most contaminant input; and Plastic Lake was intermediate. The shut down of the Inco "Super stack" was followed by dramatic reductions in lichen element content and startup was followed by increases in lichen element content. Lichen element content equilibrated with the changes in contaminant deposition rate within about one growing season. The shut down of the "Super stack" also permitted the determination that the high levels of metals found in lichens at the High Falls BGC were due to the deposition of contaminants from above rather than uptake from metal-rich exposed rock.

Considering the natural variability in the concentrations of most elements measured in replicates of C. *mitis* and C. *rangiferina*, it appears that it makes little difference whether the specific distinction is made. Only in the case case of Mg and Mn were the species markedly different. P. *schreberi*, which grows at the same sites, typically element contents 3 or 4 times that of the *Cladina* species.

6. LICHEN AND MOSS INVENTORY OF BIOGEOCHEMICAL STUDY SITES

6.1. Introduction

Lichen and moss communities were inventoried in three biogeochemical study sites in Ontario. Herbarium samples were taken and information on species composition, relative abundance, plant condition, and habitat was recorded at each site.

6.2. Purpose

The objective of the **qualitative** inventory of lichen and moss species was to document and rate the condition of these plants at the biogeochemical study sites, i.e., to establish a benchmark of current conditions for future comparison. This inventory was also to provide an evaluation of these sites as cryptogam habitat.

6.3. Methods

Inventories of lichens and bryophytes were to be conducted at the APIOS Biogeochemical sites in Ontario: Plastic Lake near Dorset, High Falls near Sudbury, and Hawkeye Lake near Thunder Bay. The inventory procedures were determined in consultation with the Liaison Officer of the Ministry.

6.3.1. Equipment

A variety of equipment was used for the collection of lichens and mosses including; a knife to scrape or cut lichens and mosses from the substratum; a chisel and hammer to sample epilithic species; a 10x hand lens; plant press; compass; white paper sample bags; water proof markers to label bags; a stapler to seal sample bags; a field note book to record site descriptions; and a camera to take photographs of habitat and lichens that could not be removed from their substratum.

6.3.2. Sampling Procedure

Bulk samples were collected in all major plant communities at each BGC site. An attempt was made to sample all lichen and moss species from all substrates. Each sample was labeled in the field with the following information: site, date, habitat, substratum, condition or vitality assessment, and relative abundance. In some instances, when a lichen could not be removed from a rock face, close-up photographs were taken for later identification in the laboratory. A 35 mm SLR camera with macro lens and electronic strobe was used.

6.3.3. Sample Identification and Voucher Preparation

Bulk samples were remoistened with distilled water in the laboratory, sorted, and pressed. Voucher specimens of the species identified were prepared, assigned collection numbers, and sets were deposited in the herbaria of the regional Ministry offices and in the National Museum of Canada, in Ottawa. The taxonomy follows Thomson (1979, 1984), Brodo (1981), Brodo and Hawksworth (1977), and Hale (1979).

Information about sampling sites and voucher samples was archived in a microcomputer relational database. The reporting capabilities allowed automatic printing of the required voucher labels.

6.4. Results

The following annotated catalogue includes 105 taxa. It is based on the author's field notes, photographs and samples collected during field trips. No new species are reported for Ontario.

The nomenclature basically follows Brodo (1981), Hale (1979), and Hale and Culberson (1970), in order of precedence.

Approximately 1200 specimens were examined by the author during the course of the study. The numbers of the vouchers cited refer to the author's collection numbers. The collections from each APIOS Biogeochemical study site are grouped by species.

Relative abundance ratings in the study have been assigned on the basis of the authors field observations and not necessarily on the basis of the number of voucher samples collected. As is common in cryptogamic biogeographical inventories, these are subjective ratings. In general, the term "Common" signifies that the species was found in many places throughout the study site. "Frequent" means that the species was found in several locations but tends to have a spotty distribution. "Infrequent" indicates that the species was not encountered very often. "Rare" means that the species was only found only once or twice in the whole time the author was investigating the site. The term "Abundant" is reserved for situations where the species was not only found in may places throughout the study site, but also occurred in large quantities.

6.4.1. Hawkeye Lake

In general, the lichen and moss community at Hawkeye Lake was more diverse than at either of the other two Biogeochemical study sites. It was also the most pristine. The 83 taxa recorded rarely showed injury, discolouration or deformation that was not typical of physical damage due to factors such as invertebrate grazing or natural senescence.

Bacidia sp. Infrequent. (7630). Sterile thalli of this crustose lichen were, on occasion, found on the bases of Cedar trees.

Bacidia chlorococca. Rare. This species occurs on bark and rotting wood.

Bryoria capillaris (Ach.) Brodo & D. Hawksw. Infrequent. (8207) This species is undoubtedly more abundant than the number of collections would seem to indicate. It was collected from white birch twigs in coniferous woods.

Bryoria furcellata (Fr.) Brodo & D. Hawksw. Common. (7515, 7516, 7529, 7530, 7531, 8225) This species was found on all coniferous tree species, especially pine and spruce. It was sometimes found on lignum and fence posts.

Bryoria lanestris (Ach.) Brodo & D. Hawksw. Frequent. (7516, 7517, 7531, 7532). This dark coloured species forms typical hairy masses on twigs of black spruce, white spruce, and occasionally on white birch.

Bryoria simplicior (Vain.) Brodo & D. Hawksw. Frequent. (7516, 7517, 7531, 7532, 7915). Thalli of this species were usually found growing entangled with *B. lanestris*. When present, the greenish black soralia are characteristic of *B. simplicior*.

Caloplaca saxicola. (Hoffm.) Nordin. Infrequent. This species was observed on rock.

Cetraria ciliaris Ach. Frequent. (7483, 7505, 7810, 7883, 7917, 7918, 7919, 8150, 8153, 8169, 8209, 8206, 8481). This species was encountered regularly on branches and twigs of Balsam fir, black spruce, white birch, and white spruce in open coniferous woods. It can be differentiated from the virtually identical *C. halei* by its lighter colour, better developed marginal cilia, and its negative UV reaction.

Cetraria halei W. Culb. & C. Culb. Common. (7351, 7515, 7532, 7877, 7880, 7881, 7884, 7902, 7923, 7930, 8148, 8170) This species was commonly encountered on twigs and branches of all coniferous tree species, but especially Balsam fir, at Hawkeye Lake site. It can be told from *C. ciliaris* by its slightly darker colour, less prominent marginal cilia and a UV+ reaction.

Cetraria pinastri (Scop.) S. Gray. Common. (7319, 7480, 7516, 7517, 7620, 7804, 7805, 7806, 7878, 7888, 7984, 8109, 8182, 8183, 8186, 8232, 8329, 8330, 8331, 8339, 8340, 8341, 8343). This species was collected on lignum, rotting wood, bark of coniferous trees and white birch (especially at the base), rocks, boulders, moss over rocks, and stems of bushes in bogs. It was almost always found in association with *Parmeliopsis ambigua* which it superficially resembles, however, the bright lemon yellow colour of *C. pinastri* is distinctive when compared side to side with greenish yellow of *P. ambigua*.

Cetraria sepincola (Ehrh.) Ach. Infrequent. This species was observed on twigs.

Cladina mitis (Sandst.) Hale & W. Culb. Abundant. [Observations of *C. arbuscula* would be included here since no tests using the very poisonous PD were done in the field due to the nature of the watershed]. (7283, 7284, 7371, 7499, 7500, 7593, 7594, 7814, 8136, 8137, 8138). This species is PD- which is the most reliable feature for separating it from *C. arbuscula*. This species was abundant on rock outcrops in clearings. It sometimes formed extensive mats.

Cladina rangiferina (L.) Harm. Common. (7285, 7286, 7287, 7479, 7503, 7504, 7792, 7816, 7817, 7822, 7823, 8142, 8143, 8143, 8144). This species was common on soil and humus near clearing associated with rock outcrops.

Cladina stellaris (Opiz.) Brodo. Infrequent. This unmistakable species was observed on soil and amongst mosses.

Cladonia sp. Common. (7107, 7326, 7511, 7720, 7774, 7921). Immature squamules of *Cladonia* were commonly encountered on bases of trees, soil, stumps, fallen twigs, and charred wood. This is interpreted as indicating that colonization of substrates is still going on. This in turn means that the extremely pollution sensitive propagules of lichens are viable.

Cladonia bacillaris (Ach.) Nyl. Infrequent. This characteristic species was observed occasionally on humus, rotten logs and tree bases.

Cladonia (Ach.) Schaer. Infrequent. This species occurs on rotten wood.

Cladonia chlorophaea (Floerke ex Somm.) Spreng. [including *Cladonia merochlorphaea*, *C. cryptochlorophaea*, *C. chlorophaea*, and *C. grayi*]. Common. (7328, 7378, 7584, 7586, 7597, 7600, 7602, 7603, 7604, 7619, 7624, 7625, 7633, 7879). This species was common and widespread on soil, moss over rock, logs, and bases of black spruce and cedar trees.

Cladonia coniocraea (Floerke) Spreng. Common. (7295, 7296, 7297, 7315, 7316, 7317, 7318, 7330, 7333, 7360, 7510, 7595, 7600, 7611, 7612, 7630, 7635, 7638, 7731, 7734, 7735, 7737, 7738, 7742, 7744, 7745, 7756, 7879, 7961, 8065, 8230, 8291, 8292, 8294, 8325, 8332, 8334, 8343). This species was commonly encountered throughout the study site on soil, amongst mosses over rock, on rotten logs, and on the bases of balsam fir, black spruce, white spruce, cedar, and white birch.

Cladonia crispata (Ach.) Flot. Rare. (7502). This species was found once at Hawkeye Lake, in a clearing on thin soil over a rock outcrop.

Cladonia cristatella Tuck. Frequent. (7318). This species is often encountered on the edge of clearings growing on rotting logs, humus, organic soil and amongst moss growing over rock. The bright red apical apothecia of these "British Soldiers" are unmistakable.

Cladonia deformis (L.) Hoffm. Infrequent. (7742). This species was occasionally found on well rotted wood and soil in moist areas. Usually only a few podetia would be found together.

Cladonia fimbriata (L.) Fr. Frequent. (7489, 7508, 7361). This species was often encountered on the bases of spruce and birch trees but also occurs on thin organic soil over rocky outcrops.

Cladonia furcata (Huds.) Schrad. Frequent. (8217, 8218). This species was found on amongst mosses growing over rocks and humus in clearings.

Cladonia gracilis (L.). Willd. Infrequent. (7364). This species occurs on soil, humus and amongst mosses in open areas, especially those associated with rock outcrops.

Cladonia multiformis Merr. Frequent. (7280). This species occurs on soil, humus and amongst mosses in open areas, especially those associated with rock outcrops.

Cladonia pleurota (Floerke) Schaer. Infrequent. This species occurs on soil and moss growing over rock.

Cladonia pyxidata (L.) Hoffm. Frequent. (7770, 8210, 8212). This species was encountered on bare soil and rock outcrops.

Cladonia squamosa (Scop.) Hoffm. Infrequent. (7617). This species occurs on well rotted logs and amongst mosses on soil or boulders.

Cladonia uncialis (L.) Wigg. Frequent. (7372). This species was found on rock outcrops where it formed mats. It superficially resembles *C. mitis* but can be differentiated by its distinctive yellowish colour.

Cladonia cervicornis ssp. *verticillata* (Hoffm.) Ahti [=*Cladonia verticillata* (Hoffm.) Schaer.]. Infrequent. This species occurs on soil.

Collema fragrans (Sm.) Ach. Infrequent. (7812, 7813). This species was found only occasionally, always on the base of deciduous trees.

Dicranum sp. Common. (7292, 7293, 7294, 7298, 7299, 7300, 7366, 7367, 7404, 7407, 7480, 7493, 7565, 7619, 7622, 7758). Cushion-like colonies of *Dicranum* species of moss were common in coniferous woods.

Drepanocladus uncinatus (Hedw.) Warnst. Frequent. (7624, 7625). This species occurs on rocks, boulders, and tree bases.

Evernia mesomorpha Nyl. Common. (7315, 7316, 7319, 7331, 7332, 7354, 7515, 7517, 7529, 7531, 7532, 7722, 7723, 7728, 7730, 7811, 7833, 7834, 7842, 7877, 7881, 7913, 7914, 7936, 8004, 8007, 8054, 8055, 8146, 8151, 8180, 8205, 8206, 8316). This distinctive species was very common at the Hawkeye Lake site. It was found on branches of almost all tree species. It occasionally was found on lignum and rock.

Fistulariella dilacerata (Hoffm.) Bowler & Rund. Infrequent. (7923, 8177). This species was found on twigs of white spruce and balsam fir at about breast height.

Hypogymnia sp. Common. (7728). Healthy immature thalli of *Hypogymnia* were commonly encountered on branches, twigs and bark of trees. This is interpreted as indicating that colonization of substrates is still going on. This in turn means that the extremely pollution sensitive propagules of lichens are still viable.

Hypogymnia physodes (L.) Nyl. Very common. (7316, 7319, 7320, 7321, 7325, 7515, 7516, 7532, 7726, 7808, 7874, 7882, 7907, 7912, 7916, 7935, 7969, 7987, 7989, 8068, 8147, 8149, 8152, 8154, 8173, 8184, 8186, 8223, 8322, 8323, 8324). This species occurs on twigs and bark of coniferous and deciduous trees, lignum, and rarely on rock or soil.

Hypogymnia tubulosa Schaer.) Hav. Infrequent. (7809). This species was found on balsam fir twigs.

Lasallia papulosa (Ach.) Llano. Frequent. This species occurs on boulders and exposed rock.

Lecanora spp. Common. (7945). Species of this genus were encountered on many substrates at the Hawkeye Lake site, on tree branches and twigs, and rotting logs.

Lecidea spp. Common. (7106). Species of this genus were encountered on many substrates at the Hawkeye Lake site, on tree branches and twigs, rotting logs, chard stumps, and exposed rock.

Parmelia spp. Common. (7427, 8178, 8179). Immature thalli of *Parmelia* spp. (probably including *P. olivacea* and *P. septentrionalis*) were commonly found on branches and exposed rock.

Parmelia exasperatula Nyl. Rare. This species was keyed out in the field on a single occasion.

Parmelia olivacea (L.) Ach. Infrequent. (7506, 7729). This species was found only on the bark of white birch.

Parmelia saxatilis (L.) Ach. Common. (7315, 7535, 7569, 7596, 7601, 7631, 7632, 7636, 8293, 8295). This species superficially resembles *Parmelia sulcata* but is easily differentiated from the latter by the presence of isidia on the margins and ridges of the *P. saxatilis* thallus. It occurred on boulders, rock outcrops, moss growing over rock, lignum and bases of trees.

Parmelia septentrionalis (Lynge) Ahti. Infrequent. (7904). This species was found on the bark of balsam fir trees at about breast height.

Parmelia subaurifera Nyl. Frequent. (7906, 8194). This species occurs on tree bark, especially the smooth bark of balsam fir and white birch trees.

Parmelia subrudecta Nyl. Infrequent. This species was observed on the bark of white birch.

Parmelia sulcata Tayl. Very common. (7315, 7316, 7318, 7319, 7321, 7331, 7332, 7337, 7349, 7350, 7351, 7354, 7418, 7482, 7506, 7516, 7517, 7519, 7520, 7529, 7530, 7531, 7532, 7639, 7793, 7794, 7795, 7807, 7808, 7809, 7815, 7818, 7833, 7834, 7842, 7844, 7846, 7847, 7874, 7877, 7881, 7883, 7899, 7900, 7902, 7904, 7905, 7906, 7910, 7912, 7913, 7915, 7916, 7918, 7922, 7923, 7930, 7932, 7933, 7934, 7936, 7945, 7952, 7953, 7954, 7966, 7967, 7969, 7970, 7982, 7983, 7987, 7988, 7989, 7994, 7995, 8005, 8006, 8007, 8023, 8040, 8059, 8060, 8061, 8062, 8063, 8066, 8068, 8069, 8070, 8130, 8131, 8132, 8146, 8148, 8149, 8150, 8152, 8154, 8171, 8172, 8175, 8177, 8191, 8192, 8193, 8194, 8195, 8196, 8197, 8198, 8199, 8200, 8201, 8202, 8203, 8205, 8208, 8209, 8222, 8223, 8224, 8320, 8322, 8324, 8333). This species occurs commonly on twigs, branches, bark and bases of all tree species, soil, rock, and moss growing over rock.

Parmelia taractica Kremp. Infrequent. This species was found growing loosely attached to rock.

Parmeliopsis aleurites (Ach.) Nyl. Frequent. (7316, 7317, 7318, 7322, 7349, 7350, 7354, 7804). This species occurs on dry lignum and cedar bark.

Parmeliopsis ambiqua (Wulf.) Nyl. Frequent. (7805). This species is quite common on conifer bark at the base of the trees, and on rotting wood. It is usually found in association with *Cetraria pinastri*.

Parmeliopsis hyperopta (Ach.) Arn. Frequent. (8342, 8186). This species occurs on the base of conifers and deciduous trees, and on rotting logs, usually in association with *P. ambigua*.

Peltigera aphthosa (L.) Willd. Frequent. This species occurs amongst mosses, especially *P. schreberi*, soil and rarely over rock.

Peltigera canina (L.) Willd. var. canina. Frequent. (7614, 7616, 7324, 7334, 7335). This lichen is very variable in appearance. It occurs on boulders, amongst mosses, on thin soil over rock out crops, and occasionally on the bases of trees.

Peltigera elizabethae Gyeln. Infrequent. (7546). Occurs on soil and over mosses in open coniferous woods.

Peltigera polydactyla (Neck.) Hoffm. *sens. strict.* Infrequent. (7329, 7543). Occurs on soil and over mosses in coniferous woods.

Physcia adscendens (Fr.) Oliv. Frequent. This distinctive lichen occurs on deciduous trees and sometimes coniferous trees.

Physcia aipolia (Ehrh.) Hampe. Common. This species occurred on many of the trembling aspen trees.

Physcia dubia (Hoffm.) Lett. Infrequent. (7350, 7569). Found growing on rocks and the trunks of cedar in open woods.

Physcia millegrana Degel. Frequent. (7599, 7627, 7634, 7637). Occurs on the bases of cedar trees in open woods.

Physcia stellaris (L.) Nyl. Frequent. This species occurred on deciduous trees and balsam fir in open woods.

Pleurozium schreberi (Brid.) Mitt. Common. (7403, 7407, 8142, 8143, 8144). This feather moss occurs on soil, humus, and rock outcrops throughout the Plastic Lake study sites.

Pseudoparmelia caperata (L.) Hale [= *Parmelia caperata*] Frequent. (7323, 7355, 7356, 7357, 7420, 8059). This species was found on balsam fir, cedar, lignum and rarely, on boulders.

Psora scalaris (Ach.) Hook. Rare. This species was found once growing on a charred stump.

Ramalina spp. Infrequent. (8175). Immature thalli of this genus were encountered on twigs and branches of coniferous trees. The thalli were often in the company of *Usnea* thalli. Both species are very sensitive to the phytotoxic effects of SO_2. This is interpreted as indicating that colonization of substrates is still going on. This in turn means that the extremely pollution sensitive propagules of these lichens are still viable.

Ramalina farinacea (L.) Ach. Infrequent. (7350, 7352, 7353). The species in very sensitive to the phytotoxic effects of SO_2. It was collected only on cedar.

Ramalina americana Hale. Rare. (7934). This species was found on the trunk of balsam fir at about breast height.

Stereocaulon paschale (L.) Hoffm. Infrequent. This species occurs on soil and amongst mosses.

Stereocaulon saxatile Magn. Infrequent. (7487, 7488). This species occurs in large clearings in coniferous woods growing on exposed acidic rock.

Stereocaulon tomentosum Fr. Frequent. (7365, 8221). This species occurs on rock outcrops and thin soil over rock.

Umbilicaria muhlenbergii (Ach.) Tuck. Frequent. (7425, 7514, 7522, 7523, 7847). This species occurs on granitic biotite gneiss boulders and exposed rock in coniferous woods

Usnea cavernosa Tuck. Frequent. (7412, 7529, 7530). This species forms large pendulous masses (10-30 cm) on branches of coniferous tree species. It is most abundant in the crown of the trees.

Usnea ceratina Ach. Infrequent. (7383, 7384, 7413, 7414). This species occurs on branches of balsam fir.

Usnea hirta (L.) Wigg. [=*Usnea glabrata*]. Infrequent. (8205). This species occurs on white birch in open areas.

Usnea subfloridana Stirt. Common. (7331, 7332, 7349, 7412, 7483, 7517, 7532, 7726, 7811, 7914, 7914, 7915, 7932, 7937, 7938, 7969, 8054, 8055, 8146, 8148, 8151, 8174, 8177, 8202, 8207, 8226). Very common in trees in open woods.

Xanthoparmelia centrifuga (L.) Hale [=*Parmelia centrifuga*]. Infrequent. Observed on boulders.

Xanthoparmelia conspersa (Ach.) Hale [=*Parmelia conspersa*]. Infrequent. (8211). Found on a rocky outcrop in coniferous woods.

Xanthoparmelia taractica (Kremplh.) Hale [=*Parmelia taractica*]. Infrequent. Found occasionally on exposed acid rock.

Xanthoparmelia tasmanica (Hook. & Tayl.) Hale. [=*Parmelia tasmanica*]. Rare. (7519). This species was encountered only once, on a boulder in coniferous woods.

Xanthoria polycarpa (Ehrh.) Oliv. Infrequent. (8004,8005, 8006). This species was encountered on the bark of white spruce at about breast height in open coniferous woods.

6.4.2. High Falls

Twenty three lichen and moss taxa were encountered in the High Falls area. Many of the lichens were difficult to identify in the field, or even later in the laboratory with the aid of a microscope, because the thalli were so discoloured, distorted and eroded.

Brachythecium sp. Frequent. This moss occurs on rotting logs.

Caloplaca holocarpa (Hoffm.) Wade. Infrequent. This species was observed only on poplar trees.

Cladina arbuscula (Wallr.) Hale & Culb. Infrequent. (7778, 7779, 8368). This species was encountered on thin soil on exposed sloping rock outcrops in mixed woods. It was immediately identifiable by its coarse secund branch tips.

Cladina mitis (Sandst.) Hale & Culb. Frequent. (7303, 7363, 7775, 7776, 7777, 7780, 7781, 7782, 7783, 7784, 7785, 7786, 7787, 8366, 8367, 8371, 8373, 8374, 8375, 8416, 8425). This species was most often found growing on thin soil collected in depressions on rock outcrops. Thalli frequently appeared to be "bleached out" and were generally stunted.

Cladina rangiferina (L.) Harm. Frequent. (8360, 8361, 8368, 8369, 8371, 8372, 8386, 8387, 8388, 8389, 8390, 8391, 8392, 8393, 8394, 8395, 8396). This species occurs on humus in mixed woods or on thin soil in depressions on rock outcrops.

Cladonia botrytes (Hag.) Willd. Infrequent. (8106, 8107, 8108, 8110, 8114). This species occurs on rotting logs and lignum in mixed woods.

Cladonia chlorophaea (Floerke ex Somm.) Spreng. [including *Cladonia merochlorphaea*, *C. cryptochlorophaea*, *C. chlorophaea*, and *C. grayi*]. Frequent. (7400, 7924, 8114, 8422). This species occurs on rotting logs, humus in depressions on rock outcrops and soil. Many of the podetia were discoloured and eroded. It was not found on the bases of trees.

Cladonia coniocraea (Floerke) Spreng. Frequent. (7379, 7925, 8106, 8107, 8108, 8110, 8113, 8114). This species was found on rotting wood and lignum. Most of the thalli were discoloured and eroded. It was not found on the bases of trees.

Cladonia crispata (Ach.) Flot. Infrequent. (8362, 8363, 8364, 8365, 8376, 8413, 8429). This species

was found on thin soil in depressions on rock outcrops. Many of the thalli were discoloured and eroded.

Cladonia cristatella Tuck. Rare. (8111). This species was encountered very few times. The typically bright red apothecia were almost black in appearance. It was found on rotting logs.

Cladonia ecmocyna (Ach.) Nyl. Rare. (8421, 8423). This species was collected from thin soil in a depression on a rock outcrop in mixed woods. The podetia were stunted and discoloured.

Cladonia multiformis Merr. Rare. (8410, 8430). Stunted and discoloured podetia of this species were encountered very few times on thin soil in depressions on rock outcrops in mixed woods.

Cladonia pleurota (Floerke) Schaer. Infrequent. (7302, 8424). This species was encountered a few times on thin soil in depression on rock outcrops. The thalli were always badly eroded and discoloured which made conclusive identification difficult.

Cladonia sp. Infrequent. (7929, 7398, 8024). Eroded and discoloured podetia and squamules of *Cladonia* were encountered on logs, soil and rock. These thalli were too damaged, discoloured or distorted to permit identification to species. Some could be recognized as belonging to the Subsections Cocciferae, Thallostelides, and Cladoniae.

Cladonia uncialis (L.) Wigg. Frequent. (7303, 7363, 8385, 8414, 8418, 8419, 8420, 8431). This species forms small mats on rock outcrops in areas surrounded by mixed woods.

Parmelia sulcata Tayl. Frequent. This species occurs on twigs and bark of poplar and maple.

Plagiomnium sp. Infrequent. This moss was sometimes found on rotting logs.

Polytrichum piliferum Hedw. Frequent. (7398). This moss was found on rock outcrops. It was generally eroded and discoloured.

Stereocaulon paschale (L.) Hoffm. Infrequent. (7398). Stunted, eroded and discoloured thalli of this lichen were encountered a few times on rock outcrops in mixed woods.

Umbilicaria deusta (L.) Baumg. Frequent. (7876, 7901, 7926, 7928). Small thalli of this species were found on NNE-facing rock outcrops in mixed woods. The thalli were never as large or luxuriant as those collected in northern Ontario.

Umbilicaria hirsuta (Sw.) Hoffm. Infrequent. This species was observed on rock outcrops where it was locally common.

Umbilicaria hyperborea (Ach.) Ach. Infrequent. This species was observed on rock outcrops where it was locally abundant.

Umbilicaria muhlenbergii (Ach.) Tuck. Rare. This species was found on a N-facing rock face near the edge of a mixed wood forest by a small intermittent run-off channel.

6.4.3. Plastic Lake

Forty-one lichen and moss taxa were encountered in the Plastic Lake area. Many species were stunted and discoloured.

Bacidia sabuletorum (Schreb.) Lett. Frequent (7120): This species was frequently found on terricolous mosses and bark at the base of trees in Maple-Oak woods. It was generally abundantly granulose and rarely produced apothecia.

Bryoria furcellata (Fr.) Brodo & D. Hawksw. Rare. (7865) Poorly developed, brittle (apparently

dead) thalli of this lichen were collected from dead lower twigs of white pine adjacent to Maple-Oak woods

Cetraria ciliaris (Ach.). Rare. (8008). A single malformed specimen was collected on Red Oak in Maple-Oak woods This species can be differentiated from the more common *C. halei* (Culb.) by its lack of fluorescence when the medulla is exposed to UV light.

Cladina arbuscula (Wallr.) Hale & Culb. Rare. (7124). Stunted thalli of this species were found growing on the ground in clearings amongst white pine trees. Without a PD test, this species is difficult to differentiate from the much more common *C. mitis* (q.v.).

Cladina mitis (Sandst.) Hale & Culb. Common. (7109, 7126, 7249, 7314, 7557, 7607, 8159, 8160, 8161). This species was found in many places in the vicinity of the Plastic Lake Biogeochemical study site. It was sometimes locally abundant in growing over rock outcrops in clearings, but was almost always stunted and discoloured.

Cladina rangiferina (L.) Nyl. Common. (7115, 7121, 7144, 7245, 7306, 7313, 7343, 7346, 7347, 7557, 7578, 7609, 7762, 8233, 8237, 8245). This species is the "true" reindeer lichen. It was the most abundant lichen species at the Plastic Lake Biogeochemical monitoring site. It was found throughout the area in exposed areas on thin soil amongst mosses or over rock outcrops. The blue-grey colour and tips drooping in one direction make it easy to identify. Relative to samples from northern Ontario, specimens from the Plastic Lake site were stunted and frequently discoloured.

Cladina stellaris (Opiz) Brodo. Frequent. (8238, 8245, 8246, 8248). This species was sometimes found in exposed areas, growing amongst swards of *C. mitis* and *C. rangiferina*. The tightly branched, rounded tufts of this species make it unmistakable. It was never conspicuously discoloured or stunted.

Cladonia sp. Frequent. (7131, 7344, 7348, 7605, 8000, 8001, 8076, 8080, 8081, 8082, 8083) Sterile, unidentifiable *Cladonia* squamules were frequently encountered on rotten wood, humus, soil, and moss over rocks in shaded clearings in Maple-Oak woods

Cladonia cenotea (Ach.) Schaer. Infrequent. (7117, 7308). Stunted and discoloured thalli of this species were found on well rotted wood on the ground in Maple-Oak woods.

Cladonia chlorophaea (Floerke ex Somm.) Spreng. Infrequent. (7114, 7339). Stunted podetia of this species were found on rotting wood. Sterile squamules of *Cladonia* commonly encountered may have been this species.

Cladonia coccifera (L.) Willd. Frequent. (7341, 8164, 8168). Generally widespread and well developed with large bright red apothecia in more northerly areas, this species was discoloured and eroded at the Plastic Lake site. The apothecia were very dark red-brown to black. It was collected from thin soil over rock in Maple-Oak woods.

Cladonia coniocraea (Floerke) Spreng. (7550) Rare. This species is generally common on humus and rotting logs in closed woods. Hale (1979) reports it as being "probably the most frequently collected pointed *Cladonia* without apothecia." At the Plastic Lake site it was rarely encountered; and then it was stunted and discoloured.

Cladonia crispata (Ach.) Flot. Frequent. (7118, 7146, 7174, 7243, 7244, 7556, 7557, 7244). Stunted thalli of this species were collected on soil and among mosses in Maple-Oak woods.

Cladonia deformis (L.) Hoffm. Frequent. (7108, 7247, 7303, 7551, 7553, 7554, 7555, 7577, 7579, 7724, 8162, 8166, 8167, 8235, 8249, 8250). Thalli of this species were typically stunted, browned and discoloured. It was collected on rotting logs and moist organic soils in open areas of Maple-Oak woods.

Cladonia furcata (Huds.) Schrad. Infrequent. (8244). This species was found on humus and on moss covered rocks, usually in shaded areas.

Cladonia multiformis Merr. Frequent. (7113, 7117, 7305, 7551, 7553, 7246). This species was frequently encountered on soil amongst mosses but was never abundant. Most thalli were discoloured and stunted.

Cladonia pleurota (Flk.) Schaer. Common. (7108, 7116, 7143, 7147, 7150, 7307, 7309, 7345, 7549, 7558, 8265, 7549, 7767). This species was common on soil and humus over rocks, but it was never abundant. Most of the specimens collected were eroded and discoloured.

Cladonia pyxidata (L.) Hoffm. Common. (7120, 7147, 7339, 7562, 8145, 7241, 7242, 7724, 7768). This species was common on humus and soil over rocks in open areas. It was frequently eroded and discoloured. These conditions were not typical of sun-burning.

Cladonia squamosa (Scop.) Hoffm. Infrequent. (7126). This species was encountered only a few times at the Plastics Lake site. It occurred in shaded areas on logs and moss. It was often stunted and discoloured. It could be confused with deformed C. *multiformis* but it fluoresces brilliant white in UV light.

Cladonia strepsilis (Ach.) Vain. Infrequent. (8072, 8077, 8264). This species was found growing as compact mats on soil in open areas and between rocks. No podetia were noted. The usually creamy white lower surface of the well developed squamules were often discoloured to brownish.

Cladonia turgida (Ehrh.) Hoffm. Rare. (7557). This species was encountered only a few times and the colonies were never extensive. The primary squamules were large and well developed. Rather than being typically chalky white, the undersides of the squamules had a brownish cast.

Cladonia uncialis (L.) Wigg. Common. (7116, 7118, 7123, 7145, 7153, 7248, 7312, 7314, 7338, 7342, 7558, 8240, 7579, 7248). This species was common on soil and amongst mosses in open areas. It was frequently discoloured and stunted. Inexperienced collectors often confuse this species with *Cladina* which it superficially resembles.

Dermatocarpon miniatum (L.) Mann. Infrequent. (7866). Small poorly developed specimens of this species were occasionally encountered on on rock outcrops.

Dicranum sp. Frequent. (7131). Sterile colonies of *Dicranum* were encountered on rotten wood and humus over rock.

Hypogymnia physodes (L.) Nyl. Common. (7895, 7896, 7980, 7981, 8078). This foliose lichen was commonly encountered on twigs, wood and bark of Maple, Oak and Pine. The thalli were often stunted and had a dark splotchy appearance instead of being light mineral grey in colour. Soralia were small, poorly formed and often barren.

Lecanora impudens Degel. Frequent. (7864, 7898). This lichen usually occurred as a sterile greenish grey crust on bark with discrete soralia which can run together leaving older parts of the thallus a mass of soredia. It was collected from Maple and Oak bark.

Lecidea granulosa (Ehrh.) Ach. Infrequent. (7127). This species was sometimes encountered on soil in Maple-Oak woods.

Lepraria finkii (B. de Lesd.) R. Harris, ined. (7980). Infrequent. This species was collected from the base of White Pine trees. It may have been more common but similar crusts were not sufficiently developed to be identified.

Nephroma resupinatum (L.) Ach. Rare. This species occurs on the base of poplar trees.

Parmelia rudecta Ach. Frequent. (7864, 7867). Small thalli of this species, often discoloured and eroding, were frequently encountered on Oak bark. The surface of the thalli were often densely isidiate.

Parmelia subaurifera Nyl. Infrequent. (8009). Several badly eroded thalli of this species were found on the bark of Oak trees. Remnants of what appeared to be former thalli were encountered not uncommonly but their identity could not be confirmed.

Parmelia sulcata Tayl. Common. (7896, 7898, 7975, 7990, 7991, 7998, 7999, 8013, 8017, 8018, 8019). This species was commonly encountered on bark and twigs of Maple and Oak, wood and occasionally rocks. The thalli generally had a reddish-brown discolouration and older parts were often badly eroded.

Parmelia soredica Nyl. [=*Parmelia ulophyllodes*] Rare. (7976, 8013). This species was encountered occasionally on Oak. The typical marginal soralia were generally badly eroded or absent, and the thalli were darker green rather than yellowish green.

Parmelia taractica Kremp. [=*Xanthoparmelia taractica*] Rare. (7978). This species was found only a few times on rock. The thalli were discoloured and the older central portions had been considerably eroded.

Polytrichum juniperinum Hedw. Common. (7343, 7557, 7554, 7724). This species occurs on soil and rocks in dry partially exposed areas in Maple-Oak woods.

Polytrichum piliferum Hedw. Common. (7174, 7554, 7556, 7562). This species occurs on thin soil over rock in exposed dry clearings on the ground in Maple-Oak woods

Scoliosporum chlorococcum (Graewe ex Stenh.) [=*Bacidia chlorococca*] Frequent. (7114) A sterile, dark green, granulose crustose lichen commonly found on shaded bark and wood, and on lignum on the ground in Maple-Oak woods.

Stereocaulon paschale (L.) Hoffm. Frequent. (7142, 7250, 7340, 8263). Stunted thalli of this species were frequently encountered on humus and amongst mosses in Maple-Oak woods.

Stereocaulon saxatile Magn. Frequent. (7765, 7766). Stunted thalli of this species were frequently encountered on rock in Maple-Oak woods.

Stereocaulon tomentosum Fr. Frequent. (7724, 7978, 8266). Stunted thalli of this species were frequently encountered on sandy soil and on exposed rock. This species can be readily separated from *S. paschale* by the presence of conspicuous and continuous tomentum on its podetia.

Umbilicaria deusta (L.) Baumg. Infrequent. (7868, 8084). This species was collected on exposed rock.

6.5. Assessment of BGC Sites as Cryptogam Habitat

The cryptogamic flora at the Hawkeye Lake Biogeochemical study site was the most undisturbed or intact of the three sites examined. The flora of the other two sites, High Falls, near Sudbury, and Plastic Lake, near Dorset, had been damaged.

High Falls had a poor and depauperate cryptogamic flora, relative to that of Hawkeye Lake. The major lichen communities surviving were found in protected microclimates or were acidophilic lichen communities growing on sloping rock outcrops where water runs off quickly. Almost no lichens or mosses occur on tree branches, twigs or bark above 10 cm from ground level. Epiphytic fruticose lichens were totally absent. Lichens examined were typically discoloured, stunted and eroded. Very few signs of propagation were observed, rather, the cryptogamic flora appeared to consist mainly of remnant communities of pollution resistant species.

Plastic Lake had a richer cryptogamic flora than High Falls but poorer than that of Hawkeye Lake. Many of the species found at the Plastic Lake site were stunted, discoloured, and eroded. No epiphytic fruticose lichens and very few epiphytic foliose lichens were observed. The cryptogamic flora was dominated by a comparatively small number of terricolous species at Plastic Lake, whereas at Hawkeye Lake the flora consisted of a diverse assortment of terricolous and epiphytic crustose, foliose and fruticose species.

6.6. Conclusions

The cryptogamic flora at the Hawkeye Lake site in NW Ontario were relatively undisturbed. In contrast, flora at the High Falls site, near Sudbury, had been severely damaged. The remaining lichen communities at that site appear to be composed largely of acidophilic species. At Plastic Lake, south of Dorset, the cryptogamic flora had started to show impact but the damage was not as severe as at High Falls. The lichen flora at Plastic Lake was less diverse than at Hawkeye Lake, and many of the species are stunted, discoloured, and eroded.

7. POPULATION DYNAMICS

7.1. Introduction

Population dynamics in mosses and lichens could be a useful indicator of the impacts of acidic precipitation. Methods of monitoring changes in population characteristics and physiological processes of cryptogamic plant species and relating these changes to the effects of acidic deposition are discussed in this section.

7.2. Purpose

The feasibility of various methods was to be determined for the study of possible changes in geographic distribution, population dynamics, growth, and reproductive processes of lichens and bryophytes in Ontario which could be related to acidic deposition or other long-range transport pollutants.

This report presents the results of the survey and the interpretation of their relevance. In addition, it presents a discussion of the relationships among the elemental contents of the lichens and mosses with respect to sources of the elements measured in the lichens and mosses.

7.3. Methods

It has been demonstrated that the elemental compositions of lichens and mosses become increasingly similar to those of the pollutants to which they are exposed as the pollutants or pollutant by-products accumulate in the plant tissues. Element content analyses of lichens and mosses can therefore be used to monitor acid precipitation distribution.

Several processes must be taken into consideration when studying changes in natural lichen and moss populations.

For example:

- changes in numbers may not occur;
- changes in dry weight, growth rate, morphology and reproductive success may all reflect environmental changes and/or increased interference from other species;
- a change in actual number of mature individuals is more gradual, especially when perennial species such as lichens and mosses are concerned.

All of the above are influenced by pathogens, season, biotic factors, genetic factors, microclimate and competition. These factors are in turn influenced directly by the pollution exposure history (i.e., concentration, duration, frequency, susceptibility and recovery).

Perennial lichen and moss populations respond directly to an environmental stress the same way as non-cryptogamic plant species. Over the short term, the latter have better compensatory mechanisms which operate at the expense of increased resource consumption. They gradually approach a situation where some resource becomes limited. Impact on lichen and mosses will be reflected in changes in biomass production, propagule size, propagule vitality, reproductive success, morphology, and resource pool levels. The long-term effects are not known.

Studying lichen and moss physiology or population dynamics could provide early warning indications concerning concurrent similar processes in higher plants. Many techniques are potentially useful for studying the effects of acid precipitation on lichen and moss population

dynamics. The techniques published to date were surveyed to determine their suitability and applicability to the Ontario situation.

7.4. Results and Discussion

7.4.1. Assessing Cryptogam Population Dynamics

The feasibility of using cryptogams as biological monitors of atmospheric contamination has been firmly established. It has been demonstrated that most contaminants, or their metabolic by-products, accumulate or concentrate in the tissues of moss and lichen species. Some of the contaminants (such as sulphur dioxide) result in reduced photosynthetic and respiration rates. Other contaminants, such as bioactive metals and radionuclides, are not very toxic to the cryptogamic species and they can accumulate to relatively high levels in their tissues.

Common methods used to measure contaminant impact on lichens and mosses are: (1) changes in photosynthetic rates; (2) changes in respiration rates; (3) changes in potassium leakage (K^+ efflux); (4) changes in conductivity of thallus leachates.

Fields and St. Clair (1984); reviewed the methods of evaluating SO_2 impact on certain lichen species and came to the conclusion that the most effective method for assessing short term SO_2 impact on lichens was a membrane permeability test. Significant drops in photosynthesis and respiration rates were found after longer periods of exposure to SO_2.

Photosynthetic rates have normally been measured as the rate of CO_2 absorption or O_2 evolution in the presence of light (Beekley & Hoffman, 1981) or changes in the amount of ^{14}C fixed following exposure to various pollutants (Puckett *et al.*, 1973, 1974). In both laboratory and field studies these methods have detected reduced photosynthesis following exposure to pollutants.

The most common methods of determining respiration rates have involved the use of either an oxygen electrode to measure O_2 absorption or an infra-red gas analyzer to measure CO_2 evolution (Baddeley *et al.*, 1971; Eversman, 1978) in the absence of light. Respiration rates, in those species examined, have been depressed following exposure to SO_2 (Eversman, 1978; Beekley & Hoffman, 1981). The response of mosses and lichens to heavy metals is much more varied.

Puckett (1977) has shown that K^+ efflux can be a useful experimental tool for assessing damage to lichen membranes following exposure to SO_2 and various bioactive metals (Puckett, 1976). Puckett's studies demonstrate a biphasic response of K^+ efflux with increasing concentrations of SO_2. This response curve has been used by Puckett to assess the sensitivity of a number of lichen species to SO_2 emissions. It has also been determined that the amount of K^+ lost following exposure to SO_2 increases with the length of the exposure period even at lower SO_2 concentrations, thus the extent of disturbance appears to be both time and concentration dependent (Tomassini *et al.*, 1977). Measurements of K^+ leakage have been determined using flame photometry or atomic absorption spectrophotometry.

The membrane permeability test is a simple method for determining the integrity of plasma membranes. This technique involves placing a piece of excised plant tissue in deionized water for 3-5 minutes and subsequently measuring the conductivity of the water (Elkiey & Ormrod, 1979; McKersie *et al.*, 1982; Beckerson & Hoffstra, 1980). If plasma membranes are intact, the conductivity of water will increase only slightly, while conductivity will be greatly increased if extensive membrane damage has occurred (Pearson & Henriksson, 1981). Healthy lichens exposed to SO_2 either in the laboratory or to fumes from a sulphur burner in field experiments displayed significant increases in electrolyte leakage, with concurrent increases in the conductivity of leachates.

7.4.2. Population Dynamics Feasibility Study Design

The impact of acidic precipitation on lichen-moss population dynamics could be investigated by establishing study plots at several sites known to be in zones of different acidic precipitation deposition but which are otherwise analogous. The existing APIOS Biogeochemical study sites are well suited for this purpose. Although some differences in floristic composition were found during the site inventory there is sufficient overlap to permit a valid comparison. At each site, a variety of parameters, such as membrane permeability, biomass production, net photosynthesis, respiration, chlorophyll content, annual growth, and cover could be investigated to determine their value for monitoring population dynamics. Other techniques, such as infrared photography or UV-fluorescence microscopy, could also be assayed. Seasonally and event collected precipitation data as well as current air quality monitoring data would provide the information necessary to evaluate the contributions of wet and dry deposition to elemental content and physiological status of the species being monitored.

This project would provide a means of increasing the relevance of more routine biomonitoring. This type of study would be suitable for a MSc graduate student research project.

7.5. Conclusions

Cryptogams are useful as biological monitors of atmospheric contamination because most pollutants, or their by-products, can accumulate to high levels in the tissues of these species. It is also well known that lichens and mosses are excellent bioindicators and the impacts of some contaminants such as SO_2 can be detected through measurable physiological changes.

In Ontario, the study of lichen and moss population dynamics could provide early warning indications of the impact of acidic precipitation on the environment. This should be investigated by establishing study plots at appropriate locations where the techniques discussed in this section could be used to monitor population dynamics. The data obtained from this type of study should be evaluated with respect to precipitation and air quality monitoring data.

8. SUMMARY

Comparison of elemental contents in *Cladina mitis* with those of *C.rangiferina* revealed good agreement between the two species. Plotting elemental concentration measurements for *C. mitis* against those of *C. rangiferina* demonstrates this agreement and yields correlation coefficients typically greater than 0.95.

The elemental contents of *C. mitis* and *Pleurozium schreberi* are similar but there is more variability than between *Cladina* species.

The chemistry of precipitation in Ontario is a factor contributing to the contents of some elements measured in lichens and mosses. It is not the only factor, however, nor the major one. The principal factors affecting the content of bioactive elements in lichens and mosses appear to be gaseous and particulate emissions from point sources, wind-blown dust, and elements derived from subsurface minerals dissolved in surface run-off water.

Variation was found in the elemental content of Al, Cr, Cu, Mn, Pb, and S in *C. mitis* collected in the vicinity of Sudbury over a period of two years. Element levels in *C. mitis* showed little variation over time at Hawkeye Lake, a remote site in NW Ontario. Element levels showed a large increase in concentration in samples collected near Sudbury during the period from September 1982 to May 1983. This was followed by a decrease in concentration at least until May 1984. As of July 1984 a trend of increasing concentration had developed and levels were still higher in October 1984.

A method is described for monitoring changes in lichen and moss populations which could be related to acidic deposition and other long-range transport pollutants. This method is based on map comparison techniques, using isopach and matrix product maps produced with standard normalized data, to study the relationships between elemental contents of a bioaccumulator and monitoring data gathered during the growing season of the vegetation. These mapping techniques allow contributions of various inputs to be assessed and presented as an intuitive graphic display.

Although it has been shown that lichen chemistry can be related to atmospheric deposition near point sources, the density of sampling sites was not sufficient to permit mapping the patterns of concentration in great detail. However, general regional trends similar to those described by Zakshek and Puckett (1986) in an independent study were once again clearly demonstrated in this study. It appears that the contribution of contaminants in acidic precipitation is in the most part secondary to that from other sources.

9. RECOMMENDATIONS

It is suggested that a survey of lichen and moss elemental content be made in areas experiencing maple die-back to determine if die-back potential can be related to sensitive bioindicators and thereby mapped.

It is suggested that a study of bioactive metals in small mammal tissues be conducted in areas identified as having significantly elevated metal levels in the lichen and moss biomonitoring species to determine if metals are building up in the food chain.

It is suggested that the K^+ efflux techniques be tested in conjunction with elemental analysis to attempt a calibration of the two methods. This would permit metal content of lichen thalli to be related to physiological impact as revealed by increased membrane leakage of K^+.

Significant levels of bioactive elements have accumulated in lichens and mosses at some of the sites studied. Similar accumulations may be occurring in vascular plants at those sites. It is suggested that three study sites be established, one at each of the biogeochemical study sites, to monitor for changes in forage quality.

It is suggested that growing season precipitation chemistry data (wet deposition) and growing season air monitoring chemistry (dry deposition) be investigated to see how much of the variability in the lichen and moss elemental contents can be explained by these factors. Map comparison techniques, including isopach and product maps, should be used to document the relative contribution of each factor.

Zakshek and Puckett (1986) were able to find samples adequate for analysis at several sites in southern Ontario. Their sampling sites should be included in any future repeated collection of lichen samples.

Future resurveys should concentrate on the collection of *Cladina* and *Evernia* species of lichen. The moss, *Pleurozium schreberi*, had an elemental composition which was sufficiently different from that of the lichens that it was difficult to compare them.

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APPENDIX A: **Elemental Contents of Lichen and Moss Samples Collected in Ontario.**

Location	Species	Grinding Method	Sample Type	Replicate	Date	Al µg/g	As µg/g	Ca µg/g	Cd µg/g	Cl %	Cr µg/g	Cu µg/g	Fe µg/g	Hg µg/g	Sample Number
Abitibi Canyon	*C. mitis*	W	S	A	17-Sep-84	1600		3100	0.30	<0.01	5.0	6	2500		11875
Abitibi Canyon	*C. mitis*	W	S	B	17-Sep-84	1400		2800	0.20	<0.01	4.0	5	2200		11874
Abitibi Canyon	*C. mitis*	W	S	C	17-Sep-84	1400		3100	0.30	<0.01	4.0	6	2200		11873
Abitibi Canyon	*C. rangiferina*	W	S	A	17-Sep-84	1500		3400	0.30	<0.01	5.0	7	2400		11877
Abitibi Canyon	*C. rangiferina*	W	S	B	17-Sep-84	1500		3100	0.30	<0.01	5.0	5	2300		11876
Abitibi Canyon	*C. rangiferina*	W	S	C	17-Sep-84	1500		3100	0.30	<0.01	6.0	7	2400		11878
Abitibi Canyon	*E. mesomorpha*	W	Special	Special	17-Sep-84	2400		26000	0.80	<0.01	8.0	11	3800		11881
Abitibi Canyon	*E. mesomorpha*	W	Special	Special	17-Sep-84	2700		25000	0.80	<0.01	8.0	11	4000		11880
Abitibi Canyon	*E. mesomorpha*	W	Special	Special	17-Sep-84	2400		26000	0.80	<0.01	8.0	10	3900		11879
Algonquin Park	*C. mitis*	W	S	A	23-Jul-83	670		530	0.30	<0.01	2.0	5	840		11530
Algonquin Park	*C. mitis*	W	S	B	23-Jul-83	300		490	0.20	<0.01	0.9	2	310		11531
Algonquin Park	*C. mitis*	W	S	C	23-Jul-83	550		460	0.20	<0.01	0.9	4	500		11532
Algonquin Park	*C. rangiferina*	W	S	A	23-Jul-83	600		360	0.40	<0.01	0.9	4	710		11523
Algonquin Park	*C. rangiferina*	W	S	B	23-Jul-83	310		990	0.30	<0.01	0.9	3	340		11518
Algonquin Park	*C. rangiferina*	W	S	C	23-Jul-83	340		550	0.30	<0.01	0.9	3	370		11529
Algonquin Park	*P. schreberi*	W	S	A	23-Jul-83	550		2200	0.70	<0.01	0.9	8	530		11538
Algonquin Park	*P. schreberi*	W	S	B	23-Jul-83	540		2200	0.70	0.010	2.0	11	580		11541
Algonquin Park	*P. schreberi*	W	S	C	23-Jul-83	460		3400	0.80	<0.01	1.0	11	480		11554
Attawapiskat	*H. splendens*	W	Special	Special	5-Oct-83	680		9900	0.20	0.030	2.0	6	950		11584
Attawapiskat	*T. nitens*	W	Special	Special	5-Oct-83	570		10000	0.20	0.030	2.0	5	810		11585
Attawapiskat	*U. subfloridana*	W	Special	Special	5-Oct-83	270		6600	0.20	0.020	0.9	4	340		11588
Attawapiskat	*U. subfloridana*	W	Special	Special	5-Oct-83	380		7000	0.20	0.020	0.9	4	470		11587
Bear Island	*C. mitis*	W	S	A	12-Aug-82	350	0.8	570	0.40	<0.01	1.0	7	720	0.02	12178
Bear Island	*C. rangiferina*	W	S	A	12-Aug-82	400	1.25	440	0.50	<0.01	1.0	9	870	0.07	12198
Bear Island	*P. schreberi*	W	S	A	12-Aug-82	910		2080	1.10	<0.01	4.0	18	1770		12179
Bond Tract	*P. schreberi*	W	S	A	11-Jul-82	950		8580	0.50	0.020	2.0	6	1220		12259
Bonnechere C.	*C. mitis*	W	S	A	1-Sep-82	740		1530	0.30	<0.01	2.0	2	1090		12107
Bonnechere C.	*C. mitis*	W	S	B	1-Sep-82	660		1630	0.30	<0.01	2.0	3	960		12214
Bonnechere C.	*C. rangiferina*	W	S	A	1-Sep-82	410		1940	0.40	<0.01	1.0	2	560		12098
Bonnechere C.	*C. rangiferina*	W	S	B	1-Sep-82	470		940	0.20	<0.01	1.0	2	580		12130
Bonnechere C.	*C. rangiferina*	W	S	C	1-Sep-82	1310		1220	0.30	<0.01	3.0	2	1700		12140
Bonnechere C.	*C. rangiferina*	W	S	D	1-Sep-82	480		2020	0.30	<0.01	1.0	2	550		12181
Bonnechere C.	*P. schreberi*	W	S	A	1-Sep-82	530	0.24	4660	0.50	<0.01	1.0	5	570	0.06	12209
Bonnechere C.	*P. schreberi*	L	S	B	1-Sep-82	3170	1.51	2980	0.70	<0.01	4.0	4	3300	0.20	12279
Bonnechere C.	*P. schreberi*	W	S	C	1-Sep-82	320		3640	0.30	<0.01	2.0	3	340		12104
Bonnechere C.	*P. schreberi*	W	S	D	1-Sep-82	490	0.3	4400	0.30	<0.01	2.0	3	580	0.04	12210
Bonnechere C.	*P. schreberi*	L	S	E	1-Sep-82	1410	1.64	9690	0.70	0.070	3.0	8	1570	0.15	12278
Capreol	*C. mitis*	W	S	A	7-Aug-82	570		350	0.40	<0.01	2.0	22	1210		12114
Capreol	*C. mitis*	W	S	B	7-Aug-82	620		240	0.50	<0.01	2.0	28	1870		12120
Capreol	*C. rangiferina*	W	S	A	7-Aug-82	620		270	0.60	<0.01	2.0	27	1760		12185
Capreol	*C. rangiferina*	W	S	B	7-Aug-82	560		440	0.40	<0.01	2.0	22	1490		12118
Capreol	*P. schreberi*	L	S	A	7-Aug-82	780		2120	1.00	0.010	3.0	73	1890		12150
Clarendon	*C. mitis*	W	S	A	2-Sep-82	1230		1690	0.40	<0.01	3.0	3	1940		12226
Clarendon	*C. mitis*	W	S	B	2-Sep-82	2100		2060	0.50	<0.01	4.0	2	3080		12227
Clarendon	*C. rangiferina*	W	S	A	2-Sep-82	490		1390	0.30	<0.01	1.0	3	790		12162
Clarendon	*C. rangiferina*	W	S	B	2-Sep-82	610		1510	0.30	<0.01	1.0	2	870		12204
Dalhousie-Mills	*C. rangiferina*	W	S	A	1-Sep-82	2230		780	0.50	<0.01	2.0	4	1820		12155
Dorion	*C. mitis*	W	S	A	6-Sep-82	1120		520	0.40	<0.01	2.0	2	1390		12085
Dorion	*C. mitis*	W	S	B	6-Sep-82	1140		640	0.30	<0.01	2.0	2	1170		12092
Dorion	*C. mitis*	W	S	C	6-Sep-82	990		530	0.20	<0.01	2.0	2	1200		12262
Dorion	*P. schreberi*	L	S	A	6-Sep-82	3130		7730	0.60	0.010	6.0	6	3890		12088
Dorion	*P. schreberi*	W	S	B	6-Sep-82	1820	0.61	8640	0.50	0.010	3.0	4	2220	0.08	12239
Dorion	*P. schreberi*	W	S	C	6-Sep-82	3360		11500	0.90	0.020	6.0	7	3720		12248
Dorion	*P. schreberi*	W	S	D	6-Sep-82	1440		6250	0.30	<0.01	4.0	4	1420		12282
Dorion	*P. schreberi*	W	S	E	6-Sep-82	500		4290	0.30	<0.01	1.0	4	500		12281
Dummer	*C. mitis*	W	S	A	21-Oct-82	4330		1840	0.60	<0.01	6.0	2	3640		12029
Dummer	*C. rangiferina*	W	S	A	21-Oct-82	6180		2940	0.70	<0.01	8.0	4	5230		12256
Dummer	*C. rangiferina*	W	S	B	21-Oct-82	750		3880	0.30	<0.01	2.0	3	950		12258
Dummer	*C. rangiferina*	W	S	C	21-Oct-82	1770		2150	0.50	<0.01	3.0	2	1900		12268
Dummer	*P. schreberi*	W	S	A	21-Oct-82	750		11200	0.40	0.020	2.0	4	850		12266
Dummer	*P. schreberi*	W	S	B	21-Oct-82	1540		12400	0.50	0.020	3.0	4	1660		12257
Ear Falls	*C. mitis*	W	S	A	7-Sep-82	620		710	0.20	<0.01	1.0	1	740		12054
Ear Falls	*C. mitis*	W	S	B	7-Sep-82	550		770	0.30	0.020	2.0	1	740		12073
Ear Falls	*C. mitis*	W	S	C	7-Sep-82	670		2100	0.40	<0.01	2.0	2	950		12081
Ear Falls	*C. rangiferina*	W	S	A	7-Sep-82	440		570	0.20	<0.01	1.0	1	550		12028
Ear Falls	*C. rangiferina*	W	S	B	7-Sep-82	460		920	0.20	<0.01	1.0	2	570		12058
Ear Falls	*C. rangiferina*	W	S	C	7-Sep-82	700		730	0.30	<0.01	2.0	2	910		12090
Ear Falls	*P. schreberi*	L	S	A	7-Sep-82	730		4170	0.30	<0.01	3.0	4	910		12056

Location	Species	Grinding Method	Sample Type	Replicate	Date	Al µg/g	As µg/g	Ca µg/g	Cd µg/g	Cl %	Cr µg/g	Cu µg/g	Fe µg/g	Hg µg/g	Sample Number
Ear Falls	*P. schreberi*	W	S	B	7-Sep-82	720		2950	0.30	<0.01	3.0	3	1050		12084
Ear Falls	*P. schreberi*	W	S	C	7-Sep-82	940		5180	0.40	<0.01	3.0	3	1080		12255
ELA	*C. mitis*	W	S	A	14-Sep-82	750		870	0.20	<0.01	2.0	1	720		12252
ELA	*C. mitis*	W	S	B	14-Sep-82	510		670	0.20	<0.01	1.0	1	530		12238
ELA	*C. rangiferina*	W	S	A	14-Sep-82	560	0.36	1450	0.20	<0.01	1.0	2	510	0.03	12236
ELA	*C. rangiferina*	W	S	B	14-Sep-82	500		710	0.20	<0.01	1.0	2	490		12237
ELA	*P. schreberi*	W	S	A	14-Sep-82	690	0.3	3410	1.70	0.010	3.0	5	720	0.06	12240
ELA	*P. schreberi*	W	S	B	14-Sep-82	730		3280	0.40	<0.01	5.0	5	770		12273
Elgin	*C. mitis*	W	S	A	2-Sep-82	360		690	0.20	<0.01	1.0	2	330		12102
Elgin	*C. mitis*	W	S	B	2-Sep-82	380		340	0.20	<0.01	1.0	2	380		12158
Elgin	*C. mitis*	W	S	C	2-Sep-82	480		540	0.30	<0.01	1.0	2	520		12224
Elgin	*C. rangiferina*	W	S	A	2-Sep-82	330		1060	0.20	<0.01	1.0	3	340		12168
Elgin	*C. rangiferina*	W	S	B	2-Sep-82	270		710	0.20	<0.01	0.9	2	260		12169
Elgin	*C. rangiferina*	W	S	C	2-Sep-82	460		530	0.20	<0.01	1.0	2	510		12175
Elgin	*P. schreberi*	L	S	A	2-Sep-82	690		3930	0.50	0.010	3.0	6	710		12149
Elgin	*P. schreberi*	W	S	B	2-Sep-82	850		4720	0.80	0.010	4.0	5	860		12126
Ely	*C. mitis*	W	S	A	5-Sep-82	490		320	0.20	0.050	1.0	1	780		12031
Ely	*C. mitis*	W	S	B	5-Sep-82	690		1010	0.30	<0.01	2.0	2	1240		12059
Ely	*C. mitis*	W	S	C	5-Sep-82	490		510	0.20	0.010	1.0	1	830		12071
Ely	*C. mitis*	W	S	D	5-Sep-82	640		740	0.20	0.070	2.0	2	1160		12086
Ely	*C. mitis*	W	S	E	5-Sep-82	710		880	0.20	<0.01	1.0	1	1290		12245
Ely	*C. rangiferina*	W	S	A	5-Sep-82	630		620	0.30	<0.01	2.0	2	1220		12050
Ely	*C. rangiferina*	W	S	B	5-Sep-82	640		680	<0.1	<0.01	0.9	1	1170		12053
Ely	*C. rangiferina*	W	S	C	5-Sep-82	570		750	0.20	<0.01	1.0	2	1060		12057
Ely	*C. rangiferina*	W	S	D	5-Sep-82	680		720	0.20	0.060	1.0	2	1120		12083
Ely	*P. schreberi*	L	S	A	5-Sep-82	1050		3350	0.30	0.030	2.0	4	1610		12052
Ely	*P. schreberi*	W	S	B	5-Sep-82	1540		4150	0.50	0.030	4.0	4	2030		12078
Ely	*P. schreberi*	L	S	C	5-Sep-82	920		3410	0.40	<0.01	2.0	4	1450		12067
Estaire	*C. mitis*	W	S	A	13-Aug-82	470		490	0.40	<0.01	2.0	21	710		12145
Estaire	*C. rangiferina*	W	S	A	13-Aug-82	560	1.19	460	0.40	<0.01	2.0	25	830	0.04	12131
Estaire	*C. rangiferina*	W	S	B	13-Aug-82	590		320	0.40	<0.01	2.0	27	1000		12137
Estaire	*C. rangiferina*	W	S	C	13-Aug-82	400		260	0.20	<0.01	1.0	5	390		12138
Estaire	*P. schreberi*	W	S	A	13-Aug-82	1170	1.38	2810	1.30	0.020	5.0	76	1850	0.10	12219
Eva Lake	*C. mitis*	W	S	A	12-Sep-82	390		430	0.10	0.010	1.0	1	490		12032
Eva Lake	*C. mitis*	W	S	B	12-Sep-82	410		370	0.20	<0.01	1.0	1	550		12034
Eva Lake	*C. mitis*	W	S	C	12-Sep-82	590		840	0.20	<0.01	2.0	2	900		12038
Eva Lake	*C. rangiferina*	W	S	A	12-Sep-82	480		420	0.10	<0.01	1.0	2	650		12047
Eva Lake	*C. rangiferina*	W	S	B	12-Sep-82	720		900	0.20	<0.01	2.0	2	1210		12048
Eva Lake	*P. schreberi*	L	S	A	12-Sep-82	940		3770	0.40	<0.01	3.0	4	1400		12035
Eva Lake	*P. schreberi*	W	S	B	12-Sep-82	1040		3450	0.30	<0.01	4.0	4	1560		12036
Forbes	*C. mitis*	W	S	A	6-Sep-82	710		630	0.20	<0.01	2.0	2	780		12027
Forbes	*C. mitis*	W	S	B	6-Sep-82	810		880	0.20	<0.01	2.0	2	940		12075
Forbes	*C. rangiferina*	W	S	A	6-Sep-82	700		990	0.20	<0.01	5.0	3	800		12018
Forbes	*C. rangiferina*	W	S	B	6-Sep-82	390		750	0.20	<0.01	6.0	2	440		12020
Forbes	*P. schreberi*	W	S	A	6-Sep-82	1090		5270	0.40	<0.01	6.0	5	1370		12095
Forbes	*P. schreberi*	W	S	B	6-Sep-82	1410		5040	0.50	0.020	4.0	5	1610		12235
Forbes	*P. schreberi*	W	S	C	6-Sep-82	4620		5490	0.70	0.010	9.0	8	5260		12250
Gowganda	*C. mitis*	W	S	A	1-Sep-82	390		2640	0.40	<0.01	2.0	3	480		12182
Gowganda	*C. rangiferina*	W	S	A	1-Sep-82	400		730	0.50	<0.01	2.0	3	450		12192
Gowganda	*P. schreberi*	L	S	A	1-Sep-82	880		4160	0.80	<0.01	5.0	7	1130		12200
Hawkeye Lake	*C. mitis*	W	S	A	12-Sep-82	640		2180	0.20	<0.01	2.0	2	800		12264
Hawkeye Lake	*C. mitis*	W	S	A	3-Oct-83	440		430	<0.1	<0.01	0.9	2	490		11567
Hawkeye Lake BGC	*C. mitis*	W	T	A	21-Jul-83	510		1100	0.20	<0.01	1.0	2	510	0.10	11798
Hawkeye Lake BGC	*C. mitis*	W	T	A	3-Oct-83	460		880	0.20	<0.01	1.0	2	570		11808
Hawkeye Lake BGC	*C. mitis*	W	T	A	16-May-84	540		890	0.20	<0.01	1.0	2	510		11771
Hawkeye Lake BGC	*C. mitis*	W	T	A	12-Jul-84	550		1300	0.20	<0.01	4.0	3	530		11781
Hawkeye Lake BGC	*C. mitis*	W	T	A	19-Oct-84	450		960	0.20	<0.01	3.0	2	490		11791
Hawkeye Lake	*C. mitis*	W	S	B	3-Oct-83	430		460	<0.1	<0.01	0.9	2	510		11568
Hawkeye Lake BGC	*C. mitis*	W	T	B	21-Jul-83	370		810	0.20	<0.01	2.0	2	390		11799
Hawkeye Lake BGC	*C. mitis*	W	T	B	3-Oct-83	760		920	0.20	<0.01	2.0	3	920		11809
Hawkeye Lake BGC	*C. mitis*	W	T	B	16-May-84	410		960	0.20	<0.01	0.9	2	490		11772
Hawkeye Lake BGC	*C. mitis*	W	T	B	12-Jul-84	720		1300	0.20	<0.01	8.0	3	780		11782
Hawkeye Lake BGC	*C. mitis*	W	T	B	19-Oct-84	810		1000	0.20	<0.01	2.0	2	880		11790
Hawkeye Lake	*C. mitis*	W	S	C	3-Oct-83	400		410	0.10	<0.01	0.9	4	430		11563
Hawkeye Lake BGC	*C. mitis*	W	T	C	21-Jul-83	440		980	0.20	<0.01	0.9	2	470		11800
Hawkeye Lake BGC	*C. mitis*	W	T	C	3-Oct-83	490		830	0.30	<0.01	1.0	2	510		11807
Hawkeye Lake BGC	*C. mitis*	W	T	C	16-May-84	500		740	0.20	<0.01	2.0	2	440		11773
Hawkeye Lake BGC	*C. mitis*	W	T	C	12-Jul-84	620		950	0.20	<0.01	3.0	2	630		11780
Hawkeye Lake BGC	*C. mitis*	W	T	C	19-Oct-84	530		1100	0.20	<0.01	9.0	2	580		11789
Hawkeye Lake	*C. rangiferina*	W	S	A	12-Sep-82	710		1350	0.20	<0.01	2.0	2	840		12267
Hawkeye Lake	*C. rangiferina*	W	S	A	3-Oct-83	500		510	<0.1	<0.01	1.0	3	590		11564
Hawkeye Lake BGC	*C. rangiferina*	W	T	A	21-Jul-83	410		760	0.20	<0.01	2.0	2	400		11803
Hawkeye Lake BGC	*C. rangiferina*	W	T	A	3-Oct-83	330		880	0.20	<0.01	2.0	2	360		11812

Location	Species	Grinding Method	Sample Type	Replicate	Date	Al µg/g	As µg/g	Ca µg/g	Cd µg/g	Cl %	Cr µg/g	Cu µg/g	Fe µg/g	Hg µg/g	Sample Number
Hawkeye Lake BGC	*C. rangiferina*	W	T	A	16-May-84	370		1100	0.20	<0.01	2.0	2	390		11774
Hawkeye Lake BGC	*C. rangiferina*	W	T	A	12-Jul-84	600		1200	0.20	<0.01	7.0	3	610		11783
Hawkeye Lake BGC	*C. rangiferina*	W	T	A	19-Oct-84	510		1400	0.10	<0.01	3.0	2	460		11794
Hawkeye Lake	*C. rangiferina*	W	S	B	12-Sep-82	570		1820	0.20	<0.01	1.0	3	610		12260
Hawkeye Lake	*C. rangiferina*	W	S	B	3-Oct-83	450		580	0.10	<0.01	0.9	4	490		11565
Hawkeye Lake BGC	*C. rangiferina*	W	T	B	21-Jul-83	360		1300	0.20	<0.01	0.9	2	350		11802
Hawkeye Lake BGC	*C. rangiferina*	W	T	B	3-Oct-83	450		900	0.20	<0.01	0.9	2	480		11811
Hawkeye Lake BGC	*C. rangiferina*	W	T	B	16-May-84	540		1100	0.20	<0.01	14.0	3	640		11776
Hawkeye Lake BGC	*C. rangiferina*	W	T	B	12-Jul-84	520		860	0.10	<0.01	3.0	2	500		11784
Hawkeye Lake BGC	*C. rangiferina*	W	T	B	19-Oct-84	620		1200	0.20	<0.01	11.0	3	630		11792
Hawkeye Lake	*C. rangiferina*	W	S	C	3-Oct-83	450		540	0.10	<0.01	0.9	2	490		11566
Hawkeye Lake BGC	*C. rangiferina*	W	T	C	21-Jul-83	520		970	0.20	<0.01	2.0	2	510		11801
Hawkeye Lake BGC	*C. rangiferina*	W	T	C	3-Oct-83	370		890	0.20	<0.01	2.0	2	390		11810
Hawkeye Lake BGC	*C. rangiferina*	W	T	C	16-May-84	500		1100	0.10	<0.01	6.0	3	520		11775
Hawkeye Lake BGC	*C. rangiferina*	W	T	C	12-Jul-84	550		1200	0.20	<0.01	2.0	3	530		11785
Hawkeye Lake BGC	*C. rangiferina*	W	T	C	19-Oct-84	560		860	0.10	<0.01	5.0	2	520		11793
Hawkeye Lake	*P. schreberi*	W	S	A	12-Sep-82	1230		8480	0.80	0.020	3.0	8	1290		12063
Hawkeye Lake	*P. schreberi*	W	S	A	3-Oct-83	640		2600	0.20	<0.01	1.0	5	600		11569
Hawkeye Lake BGC	*P. schreberi*	W	T	A	21-Jul-83	780		4700	0.40	<0.01	9.0	6	860		11806
Hawkeye Lake BGC	*P. schreberi*	W	T	A	3-Oct-83	710		5700	0.40	<0.01	14.0	6	860		11814
Hawkeye Lake BGC	*P. schreberi*	W	T	A	16-May-84	790		5700	0.30	<0.01	15.0	6	820		11779
Hawkeye Lake BGC	*P. schreberi*	W	T	A	12-Jul-84	1100		3900	0.30	<0.01	20.0	5	1200		11787
Hawkeye Lake BGC	*P. schreberi*	W	T	A	19-Oct-84	100		4000	0.50	<0.01	12.0	5	1000		11795
Hawkeye Lake	*P. schreberi*	W	S	B	3-Oct-83	620		2500	0.20	<0.01	1.0	4	590		11570
Hawkeye Lake BGC	*P. schreberi*	W	T	B	21-Jul-83	780		4900	0.40	<0.01	8.0	6	800		11805
Hawkeye Lake BGC	*P. schreberi*	W	T	B	3-Oct-83	680		5300	0.40	<0.01	9.0	6	730		11813
Hawkeye Lake BGC	*P. schreberi*	W	T	B	16-May-84	1100		3700	0.30	<0.01	25.0	5	1100		11778
Hawkeye Lake BGC	*P. schreberi*	W	T	B	12-Jul-84	880		5100	0.40	<0.01	17.0	6	960		11788
Hawkeye Lake BGC	*P. schreberi*	W	T	B	19-Oct-84	810		3900	0.40	<0.01	14.0	5	830		11796
Hawkeye Lake	*P. schreberi*	W	S	C	3-Oct-83	610		2700	0.20	<0.01	1.0	5	580		11571
Hawkeye Lake BGC	*P. schreberi*	W	T	C	21-Jul-83	720		4200	0.30	<0.01	5.0	5	700		11804
Hawkeye Lake BGC	*P. schreberi*	W	T	C	3-Oct-83	1100		3400	0.80	<0.01	11.0	7	1500		11815
Hawkeye Lake BGC	*P. schreberi*	W	T	C	16-May-84	800		5500	0.30	<0.01	3.0	7	820		11777
Hawkeye Lake BGC	*P. schreberi*	W	T	C	12-Jul-84	780		5500	0.40	<0.01	15.0	6	760		11786
Hawkeye Lake BGC	*P. schreberi*	W	T	C	19-Oct-84	1100		5100	0.40	<0.01	12.0	6	1000		11797
Hawkeye Lake	*P. schreberi*	W	S	D	3-Oct-83	640		2400	0.20	<0.01	1.0	4	610		11572
High Falls	*C. mitis*	W	S	A	16-Sep-82	400	0.55	280	0.20	<0.01	1.0	7	410	0.07	12041
High Falls BGC	*C. mitis*	W	T	A	4-May-83	1200		410	0.30	<0.01	2.0	23	1200		11576
High Falls BGC	*C. mitis*	W	T	A	3-Aug-83	1000		290	0.30	<0.01	1.0	19	1000		11575
High Falls BGC	*C. mitis*	W	T	A	23-Sep-83	710		520	0.30	<0.01	2.0	14	670		11580
High Falls BGC	*C. mitis*	W	T	A	15-May-84	520		550	0.30	<0.01	2.0	15	650		11829
High Falls BGC	*C. mitis*	W	T	A	5-Aug-84	610		310	0.30	<0.01	3.0	14	880		11839
High Falls BGC	*C. mitis*	W	T	A	12-Oct-84	720		390	0.30	<0.01	3.0	14	730		11847
High Falls BGC	*C. mitis*	W	T	B	15-May-84	300		640	0.60	<0.01	5.0	11	420		11826
High Falls BGC	*C. mitis*	W	T	B	5-Aug-84	510		340	0.30	<0.01	2.0	12	640		11837
High Falls BGC	*C. mitis*	W	T	B	12-Oct-84	740		530	0.40	<0.01	2.0	20	890		11846
High Falls BGC	*C. mitis*	W	T	C	15-May-84	1000		760	0.40	<0.01	3.0	25	1200		11830
High Falls BGC	*C. mitis*	W	T	C	5-Aug-84	350		630	0.20	<0.01	3.0	10	480		11838
High Falls BGC	*C. mitis*	W	T	C	12-Oct-84	770		720	0.40	<0.01	7.0	20	930		11848
High Falls	*C. rangiferina*	W	S	A	16-Sep-82	450	0.68	350	0.20	<0.01	1.0	7	440	0.04	12049
High Falls BGC	*C. rangiferina*	W	T	A	4-May-83	920		3600	1.00	0.020	1.0	23	750		11581
High Falls BGC	*C. rangiferina*	W	T	A	5-Aug-83	410		640	0.30	<0.01	0.9	12	500		11577
High Falls BGC	*C. rangiferina*	W	T	A	23-Sep-83	630		230	0.50	<0.01	0.9	13	700		11578
High Falls BGC	*C. rangiferina*	W	T	A	15-May-84	470		1100	0.40	<0.01	2.0	15	610		11833
High Falls BGC	*C. rangiferina*	W	T	A	5-Aug-84	310		780	0.30	<0.01	16.0	9	490		11841
High Falls BGC	*C. rangiferina*	W	T	A	12-Oct-84	310		830	0.30	0.400	2.0	10	400		11851
High Falls BGC	*C. rangiferina*	W	T	B	23-Sep-83	980		320	0.30	<0.01	2.0	17	950		11579
High Falls BGC	*C. rangiferina*	W	T	B	15-May-84	410		1200	0.40	<0.01	1.0	12	530		11832
High Falls BGC	*C. rangiferina*	W	T	B	5-Aug-84	390		1000	0.30	<0.01	2.0	11	500		11840
High Falls BGC	*C. rangiferina*	W	T	B	12-Oct-84	730		340	0.30	<0.01	3.0	19	1100		11849
High Falls BGC	*C. rangiferina*	W	T	C	15-May-84	520		830	0.40	<0.01	2.0	14	640		11831
High Falls BGC	*C. rangiferina*	W	T	C	5-Aug-84	370		790	0.30	<0.01	4.0	11	550		11842
High Falls BGC	*C. rangiferina*	W	T	C	12-Oct-84	390		920	0.40	<0.01	2.0	13	520		11850
High Falls BGC	*P. schreberi*	W	T	A	4-May-83	970		4400	0.90	<0.01	7.0	19	960		11835
High Falls BGC	*P. schreberi*	W	T	A	5-Aug-83	980		6100	1.60	0.020	3.0	39	1200		11589
High Falls BGC	*P. schreberi*	W	T	A	23-Sep-83	2400		3200	1.40	0.040	2.0	23	830		11583
High Falls BGC	*P. schreberi*	W	T	A	15-May-84	1200		4400	1.10	<0.01	11.0	33	1500		11834
High Falls BGC	*P. schreberi*	W	T	A	5-Aug-84	600		4600	0.90	<0.01	19.0	24	1200		11845
High Falls BGC	*P. schreberi*	W	T	A	12-Oct-84	960		5300	0.90	0.040	8.0	34	750		11852
High Falls BGC	*P. schreberi*	W	T	B	4-May-83	1400		3900	1.20	<0.01	4.0	67	2300		11586
High Falls BGC	*P. schreberi*	W	T	B	23-Sep-83	1100		3600	1.20	0.020	2.0	41	1100		11582
High Falls BGC	*P. schreberi*	W	T	B	15-May-84	740		5400	1.00	<0.01	8.0	21	800		11836
High Falls BGC	*P. schreberi*	W	T	B	5-Aug-84	610		4100	1.00	<0.01	10.0	26	1000		11844

Location	Species	Grinding Method	Sample Type	Replicate	Date	Al µg/g	As µg/g	Ca µg/g	Cd µg/g	Cl %	Cr µg/g	Cu µg/g	Fe µg/g	Hg µg/g	Sample Number
High Falls BGC	*P. schreberi*	W	T	B	12-Oct-84	720		7000	1.30	0.020	4.0	32	1100		11854
High Falls BGC	*P. schreberi*	W	T	C	5-Aug-84	570		4400	0.90	<0.01	19.0	24	920		11843
High Falls BGC	*P. schreberi*	W	T	C	12-Oct-84	610		5000	1.00	0.020	6.0	33	860		11853
Kaladar	*C. mitis*	W	S	A	2-Sep-82	650		770	0.30	<0.01	2.0	3	880		12176
Kaladar	*C. rangiferina*	W	S	A	2-Sep-82	380		440	0.20	<0.01	1.0	2	460		12134
Kaladar	*C. rangiferina*	W	S	B	2-Sep-82	260		460	0.20	<0.01	0.9	2	310		12142
Kaladar	*P. schreberi*	L	S	A	2-Sep-82	410		4130	0.40	0.020	3.0	4	440		12161
Kaladar	*P. schreberi*	W	S	B	2-Sep-82	480		2970	0.40	0.040	4.0	5	540		12221
Kaladar	*P. schreberi*	W	S	C	2-Sep-82	480		4280	0.40	0.020	3.0	4	540		12143
Kanata	*C. rangiferina*	W	S	A	22-Jul-83	500		2200	0.40	<0.01	0.9	3	520		11527
Kanata	*C. rangiferina*	W	S	B	22-Jul-83	640		3500	0.40	<0.01	1.0	3	690		11520
Kanata	*C. stellaris*	W	Special	Special	22-Jul-83	330		2500	0.30	<0.01	0.9	2	340		11528
Kanata	*H. physodes*	W	Special	Special	22-Jul-83	610		17000	0.70	0.110	1.0	6	980		11517
Kanata	*P. schreberi*	W	S	A	22-Jul-83	3100		8900	0.60	<0.01	5.0	9	340		11542
Kanata	*P. schreberi*	W	S	B	22-Jul-83	1500		6800	0.40	0.010	3.0	10	1900		11558
Killarney	*C. mitis*	W	S	A	6-Aug-82	800		200	0.40	<0.01	2.0	11	940		12115
Killarney	*C. mitis*	W	S	B	6-Aug-82	400		300	0.30	<0.01	0.9	7	440		12148
Killarney	*C. rangiferina*	W	S	A	6-Aug-82	360		500	0.30	<0.01	0.9	7	400		12156
Killarney	*P. schreberi*	L	S	A	6-Aug-82	740		3260	1.00	0.020	4.0	19	790		12147
Killarney	*P. schreberi*	W	S	B	6-Aug-82	730	0.61	3000	0.80	0.010	4.0	17	780	0.12	12166
Lac La Croix	*C. mitis*	W	S	A	13-Sep-82	630		660	0.20	<0.01	2.0	1	880		12072
Lac La Croix	*C. mitis*	W	S	B	13-Sep-82	1030		930	0.40	<0.01	2.0	2	1430		12082
Lac La Croix	*C. rangiferina*	W	S	A	13-Sep-82	900	1.25	910	0.30	<0.01	2.0	2	1320	0.21	12033
Lac La Croix	*C. rangiferina*	W	S	B	13-Sep-82	810		670	0.30	<0.01	2.0	1	1100		12040
Lac La Croix	*P. schreberi*	L	S	A	13-Sep-82	720		4350	0.40	0.010	3.0	4	860		12046
Lac La Croix	*P. schreberi*	W	S	B	13-Sep-82	1100	0.55	4140	0.40	0.010	5.0	4	1460	0.05	12232
Lively/Walden	*S. tomentosum*	W	Special	Special	1-Sep-82	4190		1200	1.30	0.010	18.0	163	8630		12188
Manitoulin Is.	*P. schreberi*	W	S	A	25-Jul-83	1200		3600	0.50	<0.01	2.0	8	1300		11539
Manitoulin Is.	*P. schreberi*	W	S	B	25-Jul-83	3300		6900	0.80	0.010	6.0	15	3500		11555
Manitoulin Is.	*P. schreberi*	W	S	C	25-Jul-83	3800		4100	0.80	0.010	7.0	20	4200		11556
Mattawa	*C. mitis*	W	S	A	9-Aug-82	340		500	0.30	<0.01	1.0	2	370		12110
Mattawa	*C. mitis*	W	S	B	9-Aug-82	280		860	0.30	<0.01	1.0	2	290		12193
Mattawa	*C. rangiferina*	W	S	A	9-Aug-82	320		650	0.30	<0.01	1.0	3	400		12125
Mattawa	*C. rangiferina*	W	S	B	9-Aug-82	250		560	0.30	<0.01	1.0	3	270		12127
Mattawa	*P. schreberi*	L	S	A	9-Aug-82	470		2830	0.90	<0.01	4.0	7	600		12099
Mattawa	*P. schreberi*	W	S	B	9-Aug-82	570		3750	0.60	<0.01	5.0	6	630		12196
McKellar	*C. mitis*	W	S	A	6-Aug-82	580		350	0.20	<0.01	2.0	3	720		12106
McKellar	*C. mitis*	W	S	B	6-Aug-82	670		360	0.30	<0.01	1.0	10	950		12154
McKellar	*C. rangiferina*	W	S	A	6-Aug-82	510	0.55	1720	0.30	<0.01	1.0	4	590	0.05	12136
McKellar	*C. rangiferina*	W	S	B	6-Aug-82	440		760	0.30	<0.01	0.9	3	520		12190
McKellar	*P. schreberi*	W	S	A	6-Aug-82	540	0.49	1940	0.40	<0.01	3.0	7	590	0.05	12112
McKellar	*P. schreberi*	L	S	B	6-Aug-82	820		2470	0.70	<0.01	2.0	11	790		12101
McKellar	*P. schreberi*	W	S	C	6-Aug-82	970		2070	0.50	<0.01	2.0	9	640		[illegible]
Moore Falls	*C. mitis*	W	S	A	29-Aug-82	1160		880	0.40	<0.01	4.0	4	2860		[illegible]
Moore Falls	*C. rangiferina*	W	S	A	29-Aug-82	1590		1190	0.60	<0.01	5.0	6	4180		[illegible]
Nakina	*C. mitis*	W	S	A	6-Sep-82	490		2450	0.20	<0.01	2.0	2	500		12079
Nakina	*C. mitis*	W	S	B	6-Sep-82	500		2820	0.20	<0.01	2.0	2	530		12249
Nakina	*C. rangiferina*	W	S	A	6-Sep-82	390		1610	0.10	<0.01	2.0	2	390		12025
Nakina	*C. rangiferina*	W	S	B	6-Sep-82	550		2220	0.20	<0.01	2.0	2	600		12030
Nakina	*C. rangiferina*	W	S	C	6-Sep-82	520		2980	0.30	0.040	12.0	3	750		12096
Nakina	*P. schreberi*	W	S	A	6-Sep-82	1010		6550	0.80	0.020	5.0	5	960		12241
Nakina	*P. schreberi*	W	S	B	6-Sep-82	870		7420	0.30	0.020	3.0	4	880		12069
Nakina	*P. schreberi*	L	S	C	6-Sep-82	1110		7220	0.30	0.080	3.0	4	1240		12070
Pickle Lake	*C. rangiferina*	W	S	A	7-Sep-82	570		1550	0.30	<0.01	40.0	11	1250		12021
Pickle Lake	*C. rangiferina*	W	S	B	7-Sep-82	420		940	0.20	<0.01	35.0	8	810		12023
Pickle Lake	*P. schreberi*	W	S	A	7-Sep-82	860		5690	0.30	<0.01	5.0	21	1560		12064
Pickle Lake	*P. schreberi*	W	S	B	7-Sep-82	590		6460	0.30	<0.01	3.0	14	1000		12065
Pickle Lake	*P. schreberi*	W	S	C	7-Sep-82	1350		5340	0.50	<0.01	4.0	21	2500		12233
Pickwick Lake	*C. mitis*	W	S	A	13-Sep-82	580		1370	0.10	<0.01	1.0	1	690		12037
Pickwick Lake	*C. mitis*	W	S	B	13-Sep-82	640		1620	0.20	<0.01	1.0	1	710		12051
Pickwick Lake	*C. rangiferina*	W	S	A	13-Sep-82	830	0.74	1590	0.20	<0.01	2.0	2	920	0.05	12080
Pickwick Lake	*C. rangiferina*	W	S	B	13-Sep-82	670		1670	0.30	<0.01	20.0	3	860		12097
Pickwick Lake	*P. schreberi*	W	S	A	13-Sep-82	1350	0.97	6170	0.40	0.020	4.0	4	1550	0.07	12060
Plastic Lake	*C. mitis*	W	S	A	30-Aug-82	620		220	0.20	<0.01	1.0	2	590		12129
Plastic Lake	*C. mitis*	W	S	A	18-Sep-82	770		2020	0.20	<0.01	2.0	3	870		12076
Plastic Lake BGC	*C. mitis*	W	T	A	20-Jul-83	310		410	0.20	<0.01	0.9	2	350		11534
Plastic Lake BGC	*C. mitis*	W	T	A	17-Jul-84	330		310	<0.1	<0.01	0.9	2	320		[illegible]
Plastic Lake BGC	*C. mitis*	W	T	A	18-Oct-84	310		240	0.20	<0.01	1.0	2	470		11819
Plastic Lake	*C. mitis*	W	S	B	30-Aug-82	460		540	0.20	<0.01	1.0	2	320		12206
Plastic Lake	*C. mitis*	W	S	B	18-Sep-82	1610		810	0.40	<0.01	3.0	3	1790		12274
Plastic Lake BGC	*C. mitis*	W	T	B	20-Jul-83	430		250	0.20	<0.01	0.9	4	840		11511
Plastic Lake BGC	*C. mitis*	W	T	B	17-Jul-84	240		260	0.20	<0.01	0.9	2	240		8561
Plastic Lake BGC	*C. mitis*	W	T	B	18-Oct-84	190		260	0.20	<0.01	0.9	2	230		11820

Location	Species	Grinding Method	Sample Type	Replicate	Date	Al µg/g	As µg/g	Ca µg/g	Cd µg/g	Cl %	Cr µg/g	Cu µg/g	Fe µg/g	Hg µg/g	Sample Number
Plastic Lake	*C. mitis*	W	S	C	30-Aug-82	590		380	0.20	<0.01	2.0	2	500		12222
Plastic Lake	*C. mitis*	W	S	C	18-Sep-82	1010		1240	0.40	<0.01	3.0	3	1220		12275
Plastic Lake BGC	*C. mitis*	W	T	C	20-Jul-83	340		390	0.30	<0.01	0.9	3	360		11514
Plastic Lake BGC	*C. mitis*	W	T	C	17-Jul-84	380		200	0.20	<0.01	0.9	2	320		8562
Plastic Lake BGC	*C. mitis*	W	T	C	18-Oct-84	280		240	0.10	<0.01	<1	2	300		11821
Plastic Lake	*C. rangiferina*	W	S	A	30-Aug-82	430	0.49	140	0.20	<0.01	1.0	2	400	0.02	12135
Plastic Lake	*C. rangiferina*	W	S	A	18-Sep-82	610		1760	0.20	<0.01	3.0	11	1040		12276
Plastic Lake BGC	*C. rangiferina*	W	T	A	20-Jul-83	250		400	0.20	<0.01	0.9	3	260		11533
Plastic Lake BGC	*C. rangiferina*	W	T	A	17-Jul-84	300		300	0.10	<0.01	1.0	2	260		8563
Plastic Lake BGC	*C. rangiferina*	W	T	A	18-Oct-84	250		220	0.20	<0.01	0.9	3	320		11824
Plastic Lake	*C. rangiferina*	W	S	B	30-Aug-82	400	0.49	480	0.30	<0.01	1.0	3	370	0.06	12186
Plastic Lake BGC	*C. rangiferina*	W	T	B	20-Jul-83	260		390	0.20	<0.01	0.9	3	270		11513
Plastic Lake BGC	*C. rangiferina*	W	T	B	17-Jul-84	170		550	0.10	<0.01	1.0	2	160		8564
Plastic Lake BGC	*C. rangiferina*	W	T	B	18-Oct-84	230		250	0.20	<0.01	0.9	2	250		11822
Plastic Lake	*C. rangiferina*	W	S	C	30-Aug-82	300		750	0.20	<0.01	4.0	2	290		12205
Plastic Lake BGC	*C. rangiferina*	W	T	C	20-Jul-83	310		530	0.20	<0.01	0.9	2	310		11519
Plastic Lake BGC	*C. rangiferina*	W	T	C	17-Jul-84	270		350	0.10	<0.01	3.0	3	240		8565
Plastic Lake BGC	*C. rangiferina*	W	T	C	18-Oct-84	220		290	0.20	<0.01	0.9	2	210		11823
Plastic Lake	*P. schreberi*	L	S	A	30-Aug-82	580		3120	0.70	0.020	5.0	6	560		12173
Plastic Lake BGC	*P. schreberi*	W	T	A	20-Jul-83	570		1700	0.60	<0.01	1.0	8	650		11540
Plastic Lake BGC	*P. schreberi*	W	T	A	17-Jul-84	610		2100	0.40	<0.01	7.0	6	520		8566
Plastic Lake BGC	*P. schreberi*	W	T	A	18-Oct-84	610		2400	0.50	<0.01	36.0	6	720		11827
Plastic Lake	*P. schreberi*	W	S	B	30-Aug-82	560	0.49	3210	0.80	<0.01	6.0	6	640	0.10	12100
Plastic Lake BGC	*P. schreberi*	W	T	B	20-Jul-83	510		2500	0.50	<0.01	2.0	3	530		11557
Plastic Lake BGC	*P. schreberi*	W	T	B	17-Jul-84	590		2400	0.30	<0.01	7.0	7	510		8567
Plastic Lake BGC	*P. schreberi*	W	T	B	18-Oct-84	360		2400	0.40	<0.01	8.0	5	450		11826
Plastic Lake	*P. schreberi*	W	S	C	30-Aug-82	780	0.8	2540	0.60	<0.01	4.0	6	840	0.09	12225
Plastic Lake BGC	*P. schreberi*	W	T	C	20-Jul-83	490		2500	0.60	<0.01	1.0	7	450		11544
Plastic Lake BGC	*P. schreberi*	W	T	C	17-Jul-84	580		2100	0.40	<0.01	9.0	6	550		8568
Plastic Lake BGC	*P. schreberi*	W	T	C	18-Oct-84	430		2100	0.50	<0.01	53.0	6	720		11825
Port Severn	*C. mitis*	W	S	A	28-Aug-82	820		650	0.30	<0.01	2.0	3	970		12119
Port Severn	*C. rangiferina*	W	S	A	28-Aug-82	300	0.55	770	0.20	<0.01	0.9	2	310	0.03	12153
Port Severn	*C. rangiferina*	W	S	B	28-Aug-82	460		530	0.40	<0.01	1.0	2	470		12212
Port Severn	*C. rangiferina*	W	S	C	28-Aug-82	330		910	0.10	<0.01	1.0	2	360		12213
Port Severn	*P. schreberi*	W	S	A	28-Aug-82	580		2940	0.50	0.010	3.0	7	620		12280
Port Severn	*P. schreberi*	L	S	B	28-Aug-82	370		2490	0.30	<0.01	2.0	4	330		12160
Pukaskwa	*C. mitis*	W	S	A	6-Nov-84	800		460	0.20	<0.01	4.0	2	650		11816
Pukaskwa	*C. rangiferina*	W	S	A	6-Nov-84	620		580	0.20	<0.01	2.0	2	570		11817
Pukaskwa	*P. schreberi*	W	S	A	6-Nov-84	1200		8300	0.60	<0.01	6.0	6	1000		11818
Ramsey	*C. mitis*	W	S	A	11-Aug-82	700		870	0.20	<0.01	2.0	3	980		12189
Ramsey	*C. mitis*	W	S	B	11-Aug-82	730		510	0.20	<0.01	2.0	24	1070		12151
Ramsey	*C. rangiferina*	W	S	A	11-Aug-82	600	0.74	460	0.20	<0.01	2.0	3	820	0.03	12117
Ramsey	*C. rangiferina*	W	S	B	11-Aug-82	590		580	0.30	<0.01	2.0	3	800		12163
Ramsey	*P. schreberi*	L	S	A	11-Aug-82	1180		2700	0.50	<0.01	3.0	7	1370		12167
Ramsey	*P. schreberi*	W	S	B	11-Aug-82	1600	0.87	4990	0.50	0.020	10.0	6	2220	0.09	12183
Remi Lake	*C. mitis*	W	S	A	10-Aug-82	540		1520	0.30	<0.01	2.0	2	530		12109
Remi Lake	*C. rangiferina*	W	S	A	10-Aug-82	360	0.49	1760	0.30	<0.01	1.0	2	340	0.02	12146
Remi Lake	*P. schreberi*	W	S	A	10-Aug-82	680	0.55	7900	0.50	<0.01	5.0	5	660	0.08	12116
Remi Lake	*P. schreberi*	L	S	B	10-Aug-82	1470		11200	0.50	0.020	6.0	6	1900		12128
S. S. Marie	*C. mitis*	W	S	A	24-Jul-83	720		700	0.30	<0.01	0.9	3	830		11524
S. S. Marie	*C. mitis*	W	S	B	24-Jul-83	580		550	0.10	<0.01	0.9	2	640		11521
S. S. Marie	*C. rangiferina*	W	S	A	24-Jul-83	450		1400	0.20	<0.01	0.9	3	520		11525
S. S. Marie	*C. rangiferina*	W	S	B	24-Jul-83	530		1100	0.20	<0.01	0.9	2	570		11526
S. S. Marie	*C. rangiferina*	W	S	C	24-Jul-83	550		800	0.10	<0.01	0.9	3	570		11510
S. S. Marie	*C. stellaris*	W	Special	Special	24-Jul-83	600		490	0.20	<0.01	0.9	2	680		11515
S. S. Marie	*P. schreberi*	W	S	A	24-Jul-83	1800		7900	0.50	0.010	1.0	8	920		11559
S. S. Marie	*P. schreberi*	W	S	B	24-Jul-83	1000		5200	0.40	<0.01	1.0	7	850		11560
S. S. Marie	*P. schreberi*	W	S	C	24-Jul-83	820		3500	0.40	<0.01	1.0	6	920		11545
Sauble	*C. mitis*	W	S	A	28-Aug-82	670		1110	0.30	<0.01	2.0	2	880		12203
Sauble	*C. mitis*	W	S	B	28-Aug-82	650		1220	0.30	<0.01	2.0	2	950		12208
Sauble	*C. rangiferina*	W	S	A	28-Aug-82	630	0.68	910	0.30	<0.01	2.0	3	760	0.14	12180
Sauble	*C. rangiferina*	W	S	B	28-Aug-82	640		1180	0.40	<0.01	1.0	2	760		12215
Sauble	*P. schreberi*	W	S	A	28-Aug-82	2430	2.18	1380	0.60	0.020	7.0	6	3090	0.14	12105
Sauble	*P. schreberi*	L	S	B	28-Aug-82	1950		2310	1.00	0.020	5.0	9	2620		12197
Smokey Falls	*C. mitis*	W	S	A	13-Sep-84	860		2100	0.20	<0.01	5.0	4	1200		11855
Smokey Falls	*C. mitis*	W	S	B	13-Sep-84	700		1600	0.20	<0.01	4.0	2	950		11856
Smokey Falls	*C. mitis*	W	S	C	13-Sep-84	900		3000	0.20	<0.01	6.0	3	1100		11857
Smokey Falls	*C. rangiferina*	W	S	A	13-Sep-84	580		1600	0.20	<0.01	3.0	2	720		11860
Smokey Falls	*C. rangiferina*	W	S	B	13-Sep-84	560		1700	0.20	<0.01	3.0	3	670		11859
Smokey Falls	*C. rangiferina*	W	S	C	13-Sep-84	650		1700	0.30	<0.01	4.0	4	810		11858
Smokey Falls	*C. stellaris*	W	Special	Special	13-Sep-84	420		1000	0.10	<0.01	2.0	2	460		11863
Smokey Falls	*C. stellaris*	W	Special	Special	13-Sep-84	380		980	0.20	<0.01	2.0	2	430		11862
Smokey Falls	*C. stellaris*	W	Special	Special	13-Sep-84	430		1100	0.20	<0.01	2.0	2	520		11861

Location	Species	Grinding Method	Sample Type	Replicate	Date	Al µg/g	As µg/g	Ca µg/g	Cd µg/g	Cl %	Cr µg/g	Cu µg/g	Fe µg/g	Hg µg/g	Sample Number
Smokey Falls	*E. mesomorpha*	W	Special	Special	13-Sep-84	1300		25000	0.60	0.010	9.0	7	2300		11866
Smokey Falls	*E. mesomorpha*	W	Special	Special	13-Sep-84	1400		24000	0.60	0.010	9.0	7	2300		11865
Smokey Falls	*E. mesomorpha*	W	Special	Special	13-Sep-84	1400		22000	0.60	0.010	11.0	7	2100		11864
Smokey Falls	*H. physodes*	W	Special	Special	15-Sep-84	1000		9000	0.70	0.120	3.0	6	1100		11869
Smokey Falls	*H. physodes*	W	Special	Special	15-Sep-84	1000		10000	0.70	0.100	3.0	5	1200		11868
Smokey Falls	*H. physodes*	W	Special	Special	15-Sep-84	1000		9900	0.70	0.110	3.0	6	1200		11867
Smokey Falls	*P. sulcata*	W	Special	Special	16-Sep-84	2300		14000	0.80	0.080	16.0	11	4100		11872
Smokey Falls	*P. sulcata*	W	Special	Special	16-Sep-84	2400		14000	0.70	0.070	18.0	12	4000		11871
Smokey Falls	*P. sulcata*	W	Special	Special	16-Sep-84	2400		15000	0.80	0.070	17.0	11	3800		11870
White River	*C. mitis*	W	S	A	25-Jul-83	560		1200	0.20	<0.01	2.0	3	720		11537
White River	*C. mitis*	W	S	B	25-Jul-83	450		900	0.20	<0.01	0.9	2	510		11535
White River	*C. mitis*	W	S	C	25-Jul-83	520		1400	0.20	<0.01	2.0	4	550		11522
White River	*C. rangiferina*	W	S	A	25-Jul-83	550		1800	0.20	<0.01	1.0	4	650		11536
White River	*C. rangiferina*	W	S	B	25-Jul-83	400		1500	0.20	<0.01	0.9	3	490		11512
White River	*C. rangiferina*	W	S	C	25-Jul-83	460		920	0.20	<0.01	1.0	2	500		11516
White River	*P. schreberi*	W	S	A	25-Jul-83	720		3800	0.30	<0.01	2.0	7	790		11562
White River	*P. schreberi*	W	S	B	25-Jul-83	640		3100	0.30	<0.01	2.0	7	710		11543
White River	*P. schreberi*	W	S	C	25-Jul-83	830		3900	0.30	0.010	2.0	8	910		11561
Whitney	*C. mitis*	W	S	A	31-Aug-82	330		1220	0.30	<0.01	1.0	2	500		12199
Whitney	*C. mitis*	W	S	B	31-Aug-82	370		530	0.20	<0.01	1.0	2	480		12164
Whitney	*C. mitis*	W	S	C	31-Aug-82	450		800	0.30	<0.01	1.0	3	980		12220
Whitney	*C. rangiferina*	W	S	A	31-Aug-82	330		790	0.30	<0.01	1.0	2	380		12184
Whitney	*C. rangiferina*	W	S	B	31-Aug-82	370		1030	0.30	<0.01	1.0	3	520		12187
Whitney	*P. schreberi*	L	S	A	31-Aug-82	580		3280	0.60	<0.01	3.0	5	550		12113
Whitney	*P. schreberi*	L	S	B	31-Aug-82	530		2800	0.50	0.010	3.0	5	600		12165
Whitney	*P. schreberi*	W	S	C	31-Aug-82	520		2200	0.40	<0.01	3.0	4	550		12170
Whitney	*P. schreberi*	W	S	D	31-Aug-82	890		3700	0.60	0.010	2.0	6	890		12195
Winisk	*Evernia/Ramalina*	W	Special	Special	4-Oct-83	670		10000	0.20	0.050	1.0	4	910		11548
Winisk	*Evernia/Ramalina*	W	Special	Special	4-Oct-83	500		6400	0.20	0.030	1.0	6	660		11552
Winisk	*Evernia/Ramalina*	W	Special	Special	4-Oct-83	1300		16000	0.10	0.060	3.0	5	1800		11549
Winisk	*Evernia/Ramalina*	W	Special	Special	4-Oct-83	1200		12000	0.20	0.060	3.0	6	1500		11550
Winisk	*Evernia/Ramalina*	W	Special	Special	4-Oct-83	650		7800	0.20	0.040	1.0	3	830		11551
Winisk	*H. physodes*	W	Special	Special	4-Oct-83	1100		16000	0.20	0.090	3.0	7	1500		11553
Winisk	*H. physodes*	W	Special	Special	4-Oct-83	1400		17000	0.20	0.150	3.0	7	1900		11546
Winisk	*H. physodes*	W	Special	Special	4-Oct-83	1600		22000	0.30	0.130	4.0	8	2400		11547
Winisk	*T. nitens*	W	Special	Special	4-Oct-83	170		9000	<0.1	0.060	1.0	4	220		11573
Winisk	*T. nitens*	W	Special	Special	4-Oct-83	180		12000	0.10	0.060	0.9	4	260		11574

Location	Species	K µg/g	Mg µg/g	Mn µg/g	N mg/g	Na µg/g	Ni µg/g	P mg/g	Pb µg/g	S %	Se µg/g	Ti µg/g	V µg/g	Zn µg/g	Sample Number
Abitibi Canyon	*C. mitis*	0.12	1100	47	3.0	120	3.0	0.31	11	0.01		160	8	17	11875
Abitibi Canyon	*C. mitis*	0.12	970	46	3.3	140	3.0	0.34	10	0.01		150	7	14	11874
Abitibi Canyon	*C. mitis*	0.13	1000	49	3.3	140	3.0	0.35	10	<0.01		170	7	16	11873
Abitibi Canyon	*C. rangiferina*	0.15	1100	64	3.5	120	4.0	0.39	12	0.02		160	7	20	11877
Abitibi Canyon	*C. rangiferina*	0.13	1000	53	3.8	120	3.0	0.38	13	0.02		160	7	15	11876
Abitibi Canyon	*C. rangiferina*	0.14	1100	55	3.9	120	4.0	0.39	12	0.02		190	7	17	11878
Abitibi Canyon	*E. mesomorpha*	0.27	1200	59	7.1	190	5.0	0.48	51	0.09		280	11	39	11881
Abitibi Canyon	*E. mesomorpha*	0.27	1300	60	7.1	190	5.0	0.38	56	0.09		280	12	42	11880
Abitibi Canyon	*E. mesomorpha*	0.26	1200	58	6.7	190	5.0	0.41	57	0.09		270	11	40	11879
Algonquin Park	*C. mitis*	0.28	300	54	5.2	36	2.0	0.60	12	0.04		70	2	84	11530
Algonquin Park	*C. mitis*	0.23	220	71	4.1	19	1.0	0.50	7	0.02		30	1	22	11531
Algonquin Park	*C. mitis*	0.25	270	68	4.1	23	1.0	0.50	7	0.02		59	1	15	11532
Algonquin Park	*C. rangiferina*	0.13	240	45	5.0	28	2.0	0.60	12	0.02		67	1	15	11523
Algonquin Park	*C. rangiferina*	0.22	290	76	6.0	20	2.0	0.90	12	0.05		26	1	23	11518
Algonquin Park	*C. rangiferina*	0.24	290	49	4.2	19	1.0	0.60	8	0.02		37	1	36	11529
Algonquin Park	*P. schreberi*	0.92	900	260	9.3	30	4.0	1.30	26	0.11		28	2	40	11538
Algonquin Park	*P. schreberi*	0.64	880	310	10.6	37	4.0	1.50	36	0.13		29	2	41	11541
Algonquin Park	*P. schreberi*	0.63	880	350	8.9	40	4.0	1.10	27	0.10		26	2	38	11554
Attawapiskat	*H. splendens*	0.41	2700	310	12.2	90	2.0	1.00	10	0.11		75	2	35	11584
Attawapiskat	*T. nitens*	0.36	2800	140	9.2	82	2.0	0.90	8	0.07		65	2	39	11585
Attawapiskat	*U. subfloridana*	0.26	1400	29	8.1	91	1.0	0.50	11	0.06		28	1	33	11588
Attawapiskat	*U. subfloridana*	0.27	1500	36	8.1	100	1.0	0.60	13	0.08		43	1	45	11587
Bear Island	*C. mitis*	0.14	290	70	5.4	50	8.0	0.40	11	0.04	0.40	48	1	20	12178
Bear Island	*C. rangiferina*	0.26	390	63	7.3	40	9.0	0.80	17	0.06	0.40	59	1	22	12198
Bear Island	*P. schreberi*	0.37	640	327	10.4	90	21.0	0.90	31	0.10		96	3	31	12179
Bond Tract	*P. schreberi*	0.49	2100	48	11.7	60	2.0	0.80	35	0.12		110	3	53	12259
Bonnechere C.	*C. mitis*	0.17	410	52	5.8	30	1.0	0.60	12	0.03		110	2	21	12107
Bonnechere C.	*C. mitis*	0.12	430	33	4.5	30	1.0	0.30	14	0.03		72	2	33	12214
Bonnechere C.	*C. rangiferina*	0.17	590	99	5.8	20	1.0	0.60	12	0.04		46	1	22	12098
Bonnechere C.	*C. rangiferina*	0.22	390	38	5.7	30	1.0	0.70	8	0.04		69	2	15	12130
Bonnechere C.	*C. rangiferina*	0.16	480	99	4.1	50	3.0	0.50	13	0.02		210	4	20	12140
Bonnechere C.	*C. rangiferina*	0.19	450	32	5.0	30	1.0	0.60	17	0.04		72	2	22	12181
Bonnechere C.	*P. schreberi*	0.33	700	26	5.5	80	1.0	0.80	23	0.06	3.03	76	2	16	12209
Bonnechere C.	*P. schreberi*	0.42	3020	77	7.0	130	3.0	0.60	21	0.06	0.26	380	7	34	12279
Bonnechere C.	*P. schreberi*	0.39	470	40	6.7	80	2.0	0.80	12	0.07		38	2	15	12104
Bonnechere C.	*P. schreberi*	0.30	650	28	5.2	70	2.0	0.70	20	0.06	0.13	55	2	21	12210
Bonnechere C.	*P. schreberi*	0.47	1530	99	10.0	70	2.0	1.70	33	0.10	0.26	140	4	134	12278
Capreol	*C. mitis*	0.12	240	25	5.9	30	28.0	0.40	18	0.03		85	2	13	12114
Capreol	*C. mitis*	0.12	220	23	4.8	40	41.0	0.30	23	0.03		93	2	13	12120
Capreol	*C. rangiferina*	0.12	230	24	4.3	30	34.0	0.30	26	0.03		99	2	14	12185
Capreol	*C. rangiferina*	0.14	290	60	5.0	40	32.0	0.40	21	0.03		78	2	15	12118
Capreol	*P. schreberi*	0.59	620	259	10.2	60	63.0	0.80	50	0.11		95	3	24	12150
Clarendon	*C. mitis*	0.15	1160	30	4.6	90	4.0	0.30	21	0.04		300	5	22	12226
Clarendon	*C. mitis*	0.14	1760	54	4.6	190	5.0	0.20	20	0.04		390	8	20	12227
Clarendon	*C. rangiferina*	0.15	600	22	6.0	40	3.0	0.30	13	0.04		120	2	22	12162
Clarendon	*C. rangiferina*	0.15	640	28	5.1	50	2.0	0.30	15	0.04		140	2	22	12204
Dalhousie-Mills	*C. rangiferina*	0.25	390	23	10.8	60	2.0	0.70	34	0.10		290	6	42	12155
Dorion	*C. mitis*	0.20	1020	25	5.4	70	2.0	0.30	15	0.03		160	3	16	12085
Dorion	*C. mitis*	0.17	900	36	4.6	60	2.0	0.40	12	0.02		120	3	15	12092
Dorion	*C. mitis*	0.15	790	42	3.3	60	1.0	0.30	14	0.01		120	3	14	12262
Dorion	*P. schreberi*	0.82	3730	475	12.5	190	4.0	1.90	21	0.09		420	12	61	12088
Dorion	*P. schreberi*	0.53	2090	261	8.0	110	3.0	1.20	18	0.07	0.02	300	7	55	12239
Dorion	*P. schreberi*	0.64	3620	630	10.7	190	4.0	1.60	23	0.09		400	10	71	12248
Dorion	*P. schreberi*	0.35	1180	37	5.7	40	3.0	0.80	21	0.07		140	2	20	12282
Dorion	*P. schreberi*	0.33	520	35	5.7	70	1.0	0.80	18	0.07		60	2	14	12281
Dummer	*C. mitis*	0.21	1190	131	6.1	70	3.0	0.40	18	0.04		520	7	27	12029
Dummer	*C. rangiferina*	0.24	1860	262	5.6	70	5.0	0.40	27	0.04		590	9	37	12256
Dummer	*C. rangiferina*	0.21	570	50	7.0	60	2.0	0.50	20	0.06		110	2	26	12258
Dummer	*C. rangiferina*	0.17	670	52	6.3	40	2.0	0.30	21	0.05		270	4	24	12268
Dummer	*P. schreberi*	0.32	790	82	7.3	90	2.0	0.40	23	0.07		81	3	25	12266
Dummer	*P. schreberi*	0.36	990	80	7.7	100	2.0	0.50	24	0.06		250	4	27	12257
Ear Falls	*C. mitis*	<0.1	300	37	4.3	30	1.0	0.30	4	0.01		73	1	12	12054
Ear Falls	*C. mitis*	0.11	310	44	4.1	150	2.0	0.30	6	0.02		58	1	14	12073
Ear Falls	*C. mitis*	0.14	500	112	5.3	40	2.0	0.50	13	0.03		53	2	22	12081
Ear Falls	*C. rangiferina*	0.13	230	33	6.5	30	1.0	0.50	7	0.01		48	1	12	12028
Ear Falls	*C. rangiferina*	0.19	300	52	5.6	40	<1	0.50	7	0.02		31	1	17	12058
Ear Falls	*C. rangiferina*	0.12	360	33	4.4	40	1.0	0.40	9	0.02		81	2	17	12090
Ear Falls	*P. schreberi*	0.49	840	403	8.3	90	2.0	1.00	11	0.06		79	2	43	12056
Ear Falls	*P. schreberi*	0.35	910	215	6.7	110	3.0	0.80	9	0.04		54	2	25	12084
Ear Falls	*P. schreberi*	0.43	1240	168	6.6	90	3.0	0.80	10	0.06		68	2	26	12255
ELA	*C. mitis*	0.13	400	66	3.6	60	1.0	0.30	6	0.02		75	1	11	12252
ELA	*C. mitis*	0.13	350	45	3.7	50	1.0	0.30	5	0.01		65	1	10	12238
ELA	*C. rangiferina*	0.17	400	95	4.4	50	<1	0.40	4	0.03	0.02	64	1	13	12236

	Species	K µg/g	Mg µg/g	Mn µg/g	N mg/g	Na µg/g	Ni µg/g	P mg/g	Pb µg/g	S %	Se µg/g	Ti µg/g	V µg/g	Zn µg/g	Sample Number
ELA	*C. rangiferina*	0.16	390	108	4.4	80	<1	0.50	4	0.02		66	1	13	12237
ELA	*P. schreberi*	0.52	1110	299	6.5	160	2.0	0.90	10	0.06	0.06	63	2	31	12240
ELA	*P. schreberi*	0.46	1080	316	6.2	90	5.0	0.80	9	0.05		80	2	46	12273
Elgin	*C. mitis*	0.14	250	65	6.4	60	<1	0.50	14	0.04		54	1	16	12102
Elgin	*C. mitis*	0.13	210	20	5.9	50	1.0	0.30	10	0.04		56	1	16	12158
Elgin	*C. mitis*	0.14	340	25	5.2	60	1.0	0.30	20	0.05		61	2	22	12224
Elgin	*C. rangiferina*	0.26	410	81	10.4	90	1.0	0.80	11	0.09		47	1	26	12168
Elgin	*C. rangiferina*	0.18	280	72	5.7	60	1.0	0.50	10	0.05		45	1	17	12169
Elgin	*C. rangiferina*	0.15	270	39	6.0	60	1.0	0.40	15	0.05		55	2	20	12175
Elgin	*P. schreberi*	0.51	870	386	13.9	130	2.0	1.10	29	0.12		100	4	38	12149
Elgin	*P. schreberi*	0.47	900	434	11.3	100	3.0	0.90	26	0.13		120	4	39	12126
Ely	*C. mitis*	0.14	220	19	6.8	330	<1	0.50	4	0.02		45	1	12	12031
Ely	*C. mitis*	0.16	470	79	6.8	90	1.0	0.60	7	0.04		55	2	19	12059
Ely	*C. mitis*	0.17	350	36	5.5	110	<1	0.40	5	0.03		40	1	14	12071
Ely	*C. mitis*	0.18	420	63	5.6	560	<1	0.40	8	0.03		46	2	18	12086
Ely	*C. mitis*	0.15	420	74	4.4	50	1.0	0.40	6	0.03		83	2	13	12245
Ely	*C. rangiferina*	0.14	320	32	5.1	80	1.0	0.40	8	0.03		62	2	13	12050
Ely	*C. rangiferina*	0.17	350	73	5.4	60	<1	0.40	3	0.03		61	1	14	12053
Ely	*C. rangiferina*	0.18	360	61	6.2	60	<1	0.50	5	0.04		60	1	14	12057
Ely	*C. rangiferina*	0.18	400	56	5.8	50	<1	0.50	6	0.03		52	2	16	12083
Ely	*P. schreberi*	0.41	940	270	8.8	20	2.0	0.80	11	0.06		82	2	26	12052
Ely	*P. schreberi*	0.45	1250	292	8.9	200	4.0	0.90	19	0.08		82	3	36	12078
Ely	*P. schreberi*	0.33	990	295	9.3	70	2.0	0.80	16	0.07		49	2	33	12067
Estaire	*C. mitis*	0.14	260	49	5.1	60	27.0	0.40	19	0.04		63	1	15	12145
Estaire	*C. rangiferina*	0.26	370	69	9.0	70	29.0	0.70	29	0.08	0.79	73	2	24	12131
Estaire	*C. rangiferina*	0.15	250	63	5.7	50	30.0	0.40	33	0.05		110	2	19	12137
Estaire	*C. rangiferina*	0.14	170	32	5.2	40	8.0	0.40	16	0.04		47	1	13	12138
Estaire	*P. schreberi*	0.72	870	650	13.0	70	81.0	1.30	71	0.14	1.38	110	4	43	12219
Eva Lake	*C. mitis*	0.14	220	37	6.1	50	<1	0.40	5	0.03		40	1	12	12032
Eva Lake	*C. mitis*	0.14	240	32	7.8	40	<1	0.50	6	0.03		50	1	12	12034
Eva Lake	*C. mitis*	0.14	310	72	6.7	50	1.0	0.50	6	0.03		71	2	17	12038
Eva Lake	*C. rangiferina*	0.17	260	37	8.6	50	<1	0.50	6	0.03		48	1	13	12047
Eva Lake	*C. rangiferina*	0.19	380	79	8.4	50	1.0	0.70	8	0.05		81	2	20	12048
Eva Lake	*P. schreberi*	0.38	800	333	13.1	90	2.0	1.20	13	0.08		95	3	38	12035
Eva Lake	*P. schreberi*	0.43	780	378	12.9	80	3.0	1.30	12	0.07		90	3	35	12036
Forbes	*C. mitis*	0.10	340	24	5.9	40	2.0	0.40	8	0.02		84	2	15	12027
Forbes	*C. mitis*	0.15	510	34	5.7	40	2.0	0.40	9	0.04		90	2	18	12075
Forbes	*C. rangiferina*	0.16	430	26	6.7	40	4.0	0.60	8	0.03		90	2	18	12018
Forbes	*C. rangiferina*	0.18	360	24	7.9	20	5.0	0.80	4	0.03		56	1	17	12020
Forbes	*P. schreberi*	0.38	1790	152	11.1	60	4.0	1.00	20	0.07		130	3	47	12095
Forbes	*P. schreberi*	0.53	1500	191	9.2	60	4.0	1.20	13	0.10		200	4	60	12235
Forbes	*P. schreberi*	0.48	3730	271	8.6	150	6.0	1.00	14	0.08		580	13	46	12250
Gowganda	*C. mitis*	0.15	330	83	4.6	100	2.0	1.00	9	0.03		65	1	25	12152
Gowganda	*C. rangiferina*	0.17	320	73	4.4	80	2.0	0.50	9	0.03		69	1	28	12192
Gowganda	*P. schreberi*	0.43	990	780	7.8	130	5.0	0.80	17	0.08		140	3	69	12200
Hawkeye Lake	*C. mitis*	0.19	640	155	5.5	50	1.0	0.70	6	0.03		83	2	20	12264
Hawkeye Lake	*C. mitis*	0.13	290	37	3.5	32	<1	0.40	7	0.02		37	1	11	11567
Hawkeye Lake BGC	*C. mitis*		270	47	4.4	33	<1	0.30	7	0.02		41	1	9	11798
Hawkeye Lake BGC	*C. mitis*	0.12	290	56	1.1	44	<1	<0.1	5	0.02		51	2	15	11808
Hawkeye Lake BGC	*C. mitis*	0.11	300	72	0.6	40	<1	<0.1	7	0.02		40	2	14	11771
Hawkeye Lake BGC	*C. mitis*	0.13	350	130	3.7	28	2.0	0.30	7	0.03		45	2	19	11781
Hawkeye Lake BGC	*C. mitis*	0.11	290	76	0.6	40	2.0	<0.1	7	0.02		45	1	15	11791
Hawkeye Lake	*C. mitis*	0.12	290	34	3.7	28	<1	0.40	8	0.01		40	1	8	11568
Hawkeye Lake BGC	*C. mitis*	0.08	260	50	2.5	33	<1	<0.1	6	0.01		31	1	9	11799
Hawkeye Lake BGC	*C. mitis*	0.11	330	71	0.9	47	1.0	<0.1	6	0.02		89	4	15	11809
Hawkeye Lake BGC	*C. mitis*	0.11	300	73	0.9	30	<1	<0.1	7	0.02		36	1	17	11772
Hawkeye Lake BGC	*C. mitis*	0.13	360	89	1.5	32	5.0	<0.1	7	0.02		86	3	16	11782
Hawkeye Lake BGC	*C. mitis*	0.12	340	80	1.8	44	1.0	0.10	7	0.02		96	3	14	11790
Hawkeye Lake	*C. mitis*	0.13	270	29	3.9	26	1.0	0.40	6	0.02		31	1	14	11563
Hawkeye Lake BGC	*C. mitis*	0.11	280	37	2.8	30	1.0	<0.1	6	0.02		36	1	11	11800
Hawkeye Lake BGC	*C. mitis*	0.11	270	69	2.6	53	<1	0.20	7	0.02		46	1	12	11807
Hawkeye Lake BGC	*C. mitis*	0.11	240	63	1.1	32	1.0	<0.1	7	0.02		40	1	14	11773
Hawkeye Lake BGC	*C. mitis*	0.12	310	86	1.0	25	1.0	<0.1	8	0.02		62	2	18	11780
Hawkeye Lake BGC	*C. mitis*	0.13	320	90	3.5	38	6.0	0.20	7	0.02		54	2	17	11789
Hawkeye Lake	*C. rangiferina*	0.20	560	85	5.0	40	1.0	0.60	8	0.03		100	2	20	12267
Hawkeye Lake	*C. rangiferina*	0.16	360	43	4.6	21	<1	0.50	6	0.02		47	1	15	11564
Hawkeye Lake BGC	*C. rangiferina*	<0.1	240	36	1.2	23	<1	0.10	7	0.01		35	1	7	11803
Hawkeye Lake BGC	*C. rangiferina*	0.11	260	50	3.2	43	1.0	0.20	5	0.01		32	1	10	11812
Hawkeye Lake BGC	*C. rangiferina*	0.16	350	92	2.7	23	2.0	0.20	6	0.03		34	1	17	11774
Hawkeye Lake BGC	*C. rangiferina*	0.16	360	110	1.0	24	4.0	<0.1	7	0.03		45	2	19	11783
Hawkeye Lake BGC	*C. rangiferina*	0.17	350	150	4.9	42	2.0	0.50	6	0.03		38	1	17	11794
Hawkeye Lake	*C. rangiferina*	0.22	550	99	5.4	40	2.0	0.60	6	0.04		91	2	21	12260
Hawkeye Lake	*C. rangiferina*	0.14	360	39	4.5	27	<1	0.50	6	0.02		36	1	14	11565

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Hawkeye Lake BGC	*C. rangiferina*	0.10	300	52	2.4	27	<1	0.20	5	0.01		25	1	8	11802
Hawkeye Lake BGC	*C. rangiferina*	0.12	260	110	4.4	45	<1	0.40	6	0.02		36	1	13	11811
Hawkeye Lake BGC	*C. rangiferina*	0.16	350	82	1.4	30	9.0	0.10	6	0.03		55	2	17	11776
Hawkeye Lake BGC	*C. rangiferina*	0.14	330	50	2.9	26	2.0	0.20	6	0.02		52	2	12	11784
Hawkeye Lake BGC	*C. rangiferina*	0.13	340	140	1.6	43	6.0	0.10	10	0.02		55	2	26	11792
Hawkeye Lake	*C. rangiferina*	0.17	370	43	5.1	25	<1	0.60	6	0.03		38	1	11	11566
Hawkeye Lake BGC	*C. rangiferina*	0.10	300	100	2.5	36	1.0	0.10	7	0.02		40	1	13	11801
Hawkeye Lake BGC	*C. rangiferina*	0.12	280	57	0.9	40	1.0	<0.1	6	0.01		31	1	12	11810
Hawkeye Lake BGC	*C. rangiferina*	0.14	330	110	1.6	23	5.0	0.10	7	0.03		42	1	16	11775
Hawkeye Lake BGC	*C. rangiferina*	0.15	360	85	3.7	26	<1	0.30	7	0.03		59	2	19	11785
Hawkeye Lake BGC	*C. rangiferina*	0.14	310	100	4.4	38	3.0	0.30	7	0.02		48	2	14	11793
Hawkeye Lake	*P. schreberi*	0.59	1820	270	16.1	80	2.0	1.70	27	0.14		120	3	68	12063
Hawkeye Lake	*P. schreberi*	0.56	1200	380	6.4	55	2.0	1.10	10	0.07		36	2	23	11569
Hawkeye Lake BGC	*P. schreberi*	0.26	1000	340	5.9	52	5.0	0.50	16	0.05		58	3	41	11806
Hawkeye Lake BGC	*P. schreberi*	0.34	810	360	4.0	63	8.0	0.30	9	0.07		65	3	65	11814
Hawkeye Lake BGC	*P. schreberi*	0.35	960	460	1.3	38	8.0	0.10	13	0.07		59	2	60	11779
Hawkeye Lake BGC	*P. schreberi*	0.27	920	350	6.8	47	11.0	0.50	19	0.07		89	3	50	11787
Hawkeye Lake BGC	*P. schreberi*	0.30	900	300	6.0		6.0	0.40	14	0.07		78	3	44	11795
Hawkeye Lake	*P. schreberi*	0.46	1100	410	7.5	61	2.0	1.20	10	0.08		33	2	19	11570
Hawkeye Lake BGC	*P. schreberi*	0.31	980	350	6.3	42	5.0	0.50	15	0.07		48	3	50	11805
Hawkeye Lake BGC	*P. schreberi*	0.38	940	340	0.9	79	6.0	<0.1	11	0.07		55	2	53	11813
Hawkeye Lake BGC	*P. schreberi*	0.27	880	360	1.1	48	13.0	<0.1	16	0.06		76	3	46	11778
Hawkeye Lake BGC	*P. schreberi*	0.38	950	400	6.8	43	8.0	0.60	14	0.07		75	3	60	11788
Hawkeye Lake BGC	*P. schreberi*	0.34	930	300	6.0	52	7.0	0.50	11	0.06		54	2	58	11796
Hawkeye Lake	*P. schreberi*	0.47	1200	370	6.7	52	2.0	1.10	12	0.07		30	2	18	11571
Hawkeye Lake BGC	*P. schreberi*	0.33	980	260	6.9	37	3.0	0.60	13	0.06		41	2	44	11804
Hawkeye Lake BGC	*P. schreberi*	0.27	780	320	1.2	78	7.0	<0.1	17	0.07		110	6	47	11815
Hawkeye Lake BGC	*P. schreberi*	0.37	920	400	0.9	47	2.0	<0.1	15	0.06		50	3	60	11777
Hawkeye Lake BGC	*P. schreberi*	0.40	1100	380	5.2	49	6.0	0.50	14	0.07		58	2	59	11786
Hawkeye Lake BGC	*P. schreberi*	0.33	1000	370	7.0	60	5.0	0.60	13	0.07		82	3	49	11797
Hawkeye Lake	*P. schreberi*	0.44	1100	300	6.9	62	1.0	1.10	12	0.06		38	2	21	11572
High Falls	*C. mitis*	0.13	170	30	6.7	40	8.0	0.50	11	0.02	0.59	50	<0.01	11	12041
High Falls BGC	*C. mitis*	0.17	300	28	7.7	45	25.0	0.60	30	0.05		100	3	19	11576
High Falls BGC	*C. mitis*	0.18	250	19	7.9	33	18.0	0.50	24	0.05		108	2	73	11575
High Falls BGC	*C. mitis*	0.16	280	50	6.6	28	14.0	0.60	22	0.05		58	2	57	11580
High Falls BGC	*C. mitis*	0.14	240	50	3.6	24	18.0	0.45	22	0.04		50	1	31	11829
High Falls BGC	*C. mitis*	0.12	200	22	5.8	23	19.0	0.40	16	0.03		73	2	23	11839
High Falls BGC	*C. mitis*	0.12	210	22	5.5	44	19.0	0.36	13	0.03		65	2	21	11847
High Falls BGC	*C. mitis*	0.15	250	57	5.1	24	13.0	0.46	14	0.02		26	1	34	11828
High Falls BGC	*C. mitis*	0.10	190	24	5.2	24	14.0	0.30	14	0.03		57	1	18	11837
High Falls BGC	*C. mitis*	0.16	270	41	7.8	34	22.0	0.62	22	0.05		76	2	25	11846
High Falls BGC	*C. mitis*	0.14	290	65	7.6	26	29.0	0.54	33	0.04		110	3	35	11830
High Falls BGC	*C. mitis*	0.15	250	90	5.4	19	11.0	0.54	8	0.03		40	1	19	11835
High Falls BGC	*C. mitis*	0.21	350	100	11.0	54	27.0	0.92	18	0.06		80	2	31	11848
High Falls	*C. rangiferina*	0.16	190	45	5.7	30	9.0	0.50	15	0.04	0.59	51	1	13	12049
High Falls BGC	*C. rangiferina*	0.71	860	130	11.0	92	39.0	1.70	45	0.15		26	3	97	11581
High Falls BGC	*C. rangiferina*	0.18	260	63	5.2	40	12.0	0.60	17	0.04		41	1	100	11577
High Falls BGC	*C. rangiferina*	0.14	230	38	6.6	34	13.0	0.40	28	0.05		67	2	21	11578
High Falls BGC	*C. rangiferina*	0.17	320	120	6.6	21	17.0	0.66	18	0.05		49	1	48	11833
High Falls BGC	*C. rangiferina*	0.17	290	98	4.7	19	19.0	0.60	10	0.03		34	1	33	11841
High Falls BGC	*C. rangiferina*	0.18	280	90	5.3	36	13.0	0.63	12	0.04		32	1	39	11851
High Falls BGC	*C. rangiferina*	0.15	300	37	7.6	52	22.0	0.50	21	0.05		80	2	120	11579
High Falls BGC	*C. rangiferina*	0.16	370	140	6.0	18	13.0	0.67	16	0.04		43	1	45	11832
High Falls BGC	*C. rangiferina*	0.16	310	110	5.4	16	14.0	0.68	14	0.04		42	1	42	11840
High Falls BGC	*C. rangiferina*	0.18	240	47	6.5	34	26.0	0.59	23	0.04		82	2	34	11849
High Falls BGC	*C. rangiferina*	0.16	280	84	5.6	21	17.0	0.53	19	0.05		57	1	36	11831
High Falls BGC	*C. rangiferina*	0.17	300	92	5.3	20	15.0	0.64	13	0.04		42	1	35	11842
High Falls BGC	*C. rangiferina*	0.20	310	130	5.5	47	14.0	0.63	15	0.04		37	1	37	11850
High Falls BGC	*P. schreberi*	0.50	1100	310	9.0	33	33.0	1.85	31	0.09		36	3	99	11835
High Falls BGC	*P. schreberi*	0.60	1500	480	17.6	124	45.0	2.20	44	0.17		55	4	190	11589
High Falls BGC	*P. schreberi*	0.89	1100	340	9.7	58	39.0	1.60	74	0.17		53	3	120	11583
High Falls BGC	*P. schreberi*	0.43	1000	240	10.7	38	40.0	1.73	38	0.09		110	4	110	11834
High Falls BGC	*P. schreberi*	0.58	1100	97	9.7	43	45.0	1.58	30	0.10		65	2	110	11845
High Falls BGC	*P. schreberi*	0.94	1200	170	11.5	89	31.0	1.90	25	0.14		56	3	140	11852
High Falls BGC	*P. schreberi*	0.51	970	710	18.3	56	70.0	2.10	69	0.17		98	5	120	11586
High Falls BGC	*P. schreberi*	0.70	1000	180	13.9	74	45.0	1.90	51	0.17		41	4	130	11582
High Falls BGC	*P. schreberi*	0.45	1200	400	11.3	31	30.0	1.81	28	0.09		41	2	130	11836
High Falls BGC	*P. schreberi*	0.56	900	170	6.6	46	36.0	1.54	29	0.10		58	3	120	11844
High Falls BGC	*P. schreberi*	0.80	1400	260	6.3	78	40.0	0.90	34	0.14		71	3	190	11854
High Falls BGC	*P. schreberi*	0.58	980	180	9.3	37	39.0	1.45	27	0.09		52	2	100	11843
High Falls BGC	*P. schreberi*	0.79	1300	240	12.5	93	35.0	2.13	38	0.11		58	2	130	11853
Kaladar	*C. mitis*	0.12	270	22	5.9	40	2.0	0.30	28	0.06		89	3	22	12176
Kaladar	*C. rangiferina*	0.12	200	20	5.2	40	<1	0.30	13	0.04		65	2	17	12134

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Kaladar	*C. rangiferina*	0.14	220	33	5.0	30	<1	0.30	14	0.03		43	1	17	12142
Kaladar	*P. schreberi*	0.52	860	512	8.3	90	2.0	0.80	20	0.08		60	2	35	12161
Kaladar	*P. schreberi*	0.53	920	437	6.5	280	3.0	0.60	24	0.09		54	3	42	12221
Kaladar	*P. schreberi*	0.53	830	390	7.3	110	2.0	0.80	27	0.08		55	3	36	12143
Kanata	*C. rangiferina*	0.21	380	17	5.0	40	<1	0.80	21	0.06		52	2	25	11527
Kanata	*C. rangiferina*	0.19	410	20	7.4	34	1.0	0.60	33	0.06		70	3	27	11520
Kanata	*C. stellaris*	0.18	320	20	5.7	29	<1	0.60	13	0.04		39	1	32	11528
Kanata	*H. physodes*	0.40	560	27	10.4	52	2.0	1.30	66	0.11		46	5	67	11517
Kanata	*P. schreberi*	0.53	2200	130	7.7	110	4.0	1.20	21	0.07		271	8	28	11542
Kanata	*P. schreberi*	0.45	1700	85	7.0	92	3.0	0.80	23	0.08		154	6	28	11558
Killarney	*C. mitis*	0.15	260	13	8.5	50	15.0	0.40	38	0.07		94	3	22	12115
Killarney	*C. mitis*	0.11	150	26	4.9	40	90.0	0.40	18	0.03		57	1	15	12148
Killarney	*C. rangiferina*	0.16	210	55	5.2	30	9.0	0.40	12	0.04		43	1	15	12156
Killarney	*P. schreberi*	0.48	730	900	13.3	50	20.0	1.70	39	0.13		78	3	68	12147
Killarney	*P. schreberi*	0.65	820	737	12.5	60	18.0	1.60	32	0.14	0.72	80	3	64	12166
Lac La Croix	*C. mitis*	0.15	460	27	4.7	40	1.0	0.40	7	0.02		56	2	13	12072
Lac La Croix	*C. mitis*	0.19	620	44	6.9	80	2.0	0.70	10	0.04		79	2	18	12082
Lac La Croix	*C. rangiferina*	0.23	560	49	8.2	60	1.0	0.80	6	0.05	0.59	88	2	18	12033
Lac La Croix	*C. rangiferina*	0.17	440	29	5.7	60	<1	0.50	7	0.03		92	2	15	12040
Lac La Croix	*P. schreberi*	0.55	1080	200	9.7	170	2.0	1.00	9	0.07		50	2	27	12046
Lac La Croix	*P. schreberi*	0.58	1470	260	6.4	170	4.0	1.00	12	0.07	0.02	93	3	33	12232
Lively/Walden	*S. tomentosum*	0.39	2150	69	7.7	190	205.0	0.60	36	0.09		780	13	45	12188
Manitoulin Is.	*P. schreberi*	0.41	990	150	9.6	32	6.0	0.60	34	0.09		160	4	50	11539
Manitoulin Is.	*P. schreberi*	0.49	1400	230	8.0	50	9.0	0.50	40	0.08		465	9	63	11555
Manitoulin Is.	*P. schreberi*	0.54	1500	250	8.1	50	9.0	0.50	41	0.08		669	10	76	11556
Mattawa	*C. mitis*	0.16	230	89	5.6	40	4.0	0.50	14	0.04		50	1	26	12110
Mattawa	*C. mitis*	0.14	250	150	5.8	30	2.0	0.60	17	0.04		50	1	25	12193
Mattawa	*C. rangiferina*	0.23	280	150	6.4	30	2.0	0.70	19	0.05		50	1	29	12125
Mattawa	*C. rangiferina*	0.21	260	121	5.5	30	2.0	0.60	18	0.04		38	1	22	12127
Mattawa	*P. schreberi*	0.39	800	526	12.0	60	5.0	1.40	33	0.08		48	2	43	12099
Mattawa	*P. schreberi*	0.48	770	695	10.0	90	5.0	1.10	23	0.10		75	2	47	12196
McKellar	*C. mitis*	0.12	220	24	7.4	40	3.0	0.40	17	0.05		110	2	18	12106
McKellar	*C. mitis*	0.14	240	26	7.1	40	3.0	0.40	20	0.05		150	3	24	12154
McKellar	*C. rangiferina*	0.18	270	31	7.8	40	3.0	0.41	19	0.06	0.33	96	2	26	12136
McKellar	*C. rangiferina*	0.16	320	36	26.0	20	3.0	1.50	17	0.05		79	1	27	12190
McKellar	*P. schreberi*	0.49	670	230	9.7	60	5.0	0.70	20	0.09	0.46	63	2	35	12112
McKellar	*P. schreberi*	0.37	870	298	12.4	60	7.0	1.00	37	0.09		93	3	84	12101
McKellar	*P. schreberi*	0.50	700	256	10.7	60	4.0	0.80	25	0.09		75	2	35	12108
Moore Falls	*C. mitis*	0.17	870	33	5.7	60	2.0	0.40	31	0.04		290	5	89	12231
Moore Falls	*C. rangiferina*	0.21	1260	51	6.7	90	3.0	0.60	43	0.06		360	7	136	12229
Nakina	*C. mitis*	0.15	690	115	5.0	70	1.0	0.60	6	0.02		58	1	19	12079
Nakina	*C. mitis*	0.18	760	150	4.1	70	1.0	0.50	5	0.02		71	1	21	12249
Nakina	*C. rangiferina*	0.18	510	91	6.2	60	<1	0.80	4	0.02		51	1	18	12025
Nakina	*C. rangiferina*	0.19	640	110	7.3	60	2.0	0.90	6	0.02		59	2	18	12030
Nakina	*C. rangiferina*	0.20	950	119	5.7	300	5.0	0.70	11	0.02		53	2	34	12096
Nakina	*P. schreberi*	0.54	1850	580	6.3	180	3.0	0.90	13	0.07		91	2	37	12241
Nakina	*P. schreberi*	0.41	1960	371	7.5	140	2.0	0.90	12	0.06		74	2	31	12069
Nakina	*P. schreberi*	0.43	1860	417	8.4	530	1.0	0.90	10	0.06		140	3	34	12070
Pickle Lake	*C. rangiferina*	0.14	440	165	4.2	60	23.0	0.50	17	0.02		67	2	55	12021
Pickle Lake	*C. rangiferina*	0.13	370	36	4.7	40	18.0	0.50	9	0.01		53	2	13	12023
Pickle Lake	*P. schreberi*	0.42	1330	511	8.7	100	4.0	1.00	14	0.07		93	2	30	12064
Pickle Lake	*P. schreberi*	0.50	1320	621	7.2	120	2.0	1.00	14	0.06		55	2	34	12065
Pickle Lake	*P. schreberi*	0.25	1340	376	8.2	130	4.0	0.80	24	0.07		170	4	32	12233
Pickwick Lake	*C. mitis*	0.15	350	38	6.7	50	<1	0.50	6	0.03		67	1	14	12037
Pickwick Lake	*C. mitis*	0.17	390	50	5.8	50	1.0	0.50	6	0.03		65	2	15	12051
Pickwick Lake	*C. rangiferina*	0.21	530	38	7.1	70	1.0	0.60	8	0.04	0.06	63	2	17	12080
Pickwick Lake	*C. rangiferina*	0.25	500	56	7.9	60	7.0	0.70	9	0.04		60	2	31	12097
Pickwick Lake	*P. schreberi*	0.48	1210	166	12.4	140	3.0	1.30	12	0.09	0.33	120	3	34	12060
Plastic Lake	*C. mitis*	0.12	180	25	6.7	40	1.0	0.30	12	0.04		79	2	19	12129
Plastic Lake	*C. mitis*	0.20	610	133	5.7	50	2.0	0.70	8	0.04		73	2	23	12076
Plastic Lake BGC	*C. mitis*	0.23	250	45	6.6	30	<1	0.30	10	0.05		35	1	22	11534
Plastic Lake BGC	*C. mitis*	0.14	220	34	7.0	19	<1	0.35	9	0.05		32	1	18	8560
Plastic Lake BGC	*C. mitis*	0.11	170	25	1.2	54	1.0	<0.1	8	0.03		34	1	14	11819
Plastic Lake	*C. mitis*	<0.1	190	81	4.8	40	1.0	0.30	10	0.04		40	1	17	12206
Plastic Lake	*C. mitis*	0.22	1300	34	4.9	60	2.0	0.40	13	0.03		150	4	20	12274
Plastic Lake BGC	*C. mitis*	0.11	230	21	6.9	24	<1	0.20	8	0.05		34	1	22	11511
Plastic Lake BGC	*C. mitis*	0.14	190	26	6.4	15	<1	0.28	10	0.04		26	1	26	8561
Plastic Lake BGC	*C. mitis*	0.11	160	26	4.0	48	<1	0.20	6	0.02		20	1	12	11820
Plastic Lake	*C. mitis*	0.10	240	58	6.3	30	2.0	0.30	12	0.05		49	2	18	12222
Plastic Lake	*C. mitis*	0.15	600	48	5.2	30	2.0	0.50	10	0.03		120	3	31	12275
Plastic Lake BGC	*C. mitis*	0.14	250	27	6.5	44	<1	0.40	14	0.04		33	1	23	11514
Plastic Lake BGC	*C. mitis*	0.12	210	19	7.3	29	<1	0.26	13	0.04		28	1	25	8562
Plastic Lake BGC	*C. mitis*	0.12	210	31	5.5	44	<1	0.29	6	0.03		28	<1	15	11821

	Species	K µg/g	Mg µg/g	Mn µg/g	N mg/g	Na µg/g	Ni µg/g	P mg/g	Pb µg/g	S %	Se µg/g	Ti µg/g	V µg/g	Zn µg/g	Sample Number
Plastic Lake	*C. rangiferina*	0.14	160	25	6.0	30	2.0	0.30	15	0.05	0.26	49	1	16	12135
Plastic Lake	*C. rangiferina*	0.14	530	126	4.1	60	2.0	0.50	14	0.02		50	2	35	12276
Plastic Lake BGC	*C. rangiferina*	0.31	270	80	6.5	28	<1	0.40	10	0.04		24	1	32	11533
Plastic Lake BGC	*C. rangiferina*	0.21	250	33	6.6	18	<1	0.40	7	0.05		21	1	18	8563
Plastic Lake BGC	*C. rangiferina*	0.14	180	26	5.9	42	<1	0.25	9	0.03		30	1	14	11824
Plastic Lake	*C. rangiferina*	0.22	310	74	7.3	40	1.0	0.50	14	0.07	0.26	64	1	23	12186
Plastic Lake BGC	*C. rangiferina*	0.16	240	33	7.8	25	<1	0.40	12	0.05		29	1	19	11513
Plastic Lake BGC	*C. rangiferina*	0.21	190	78	5.9	18	<1	0.43	8	0.03		18	1	24	8564
Plastic Lake BGC	*C. rangiferina*	0.13	180	25	5.9	37	<1	0.28	7	0.03		28	1	13	11822
Plastic Lake	*C. rangiferina*	0.20	280	81	7.8	20	1.0	0.50	27	0.05		48	1	22	12205
Plastic Lake BGC	*C. rangiferina*	0.16	250	63	5.9	30	1.0	0.50	13	0.04		29	1	19	11519
Plastic Lake BGC	*C. rangiferina*	0.16	170	41	6.3	25	2.0	0.33	8	0.04		23	1	15	8565
Plastic Lake BGC	*C. rangiferina*	0.20	210	42	6.5	45	<1	0.38	7	0.05		21	1	12	11823
Plastic Lake	*P. schreberi*	0.51	640	1120	11.3	90	3.0	1.00	28	0.11		60	2	43	12173
Plastic Lake BGC	*P. schreberi*	0.41	580	230	10.0	41	3.0	0.70	29	0.10		50	2	39	11540
Plastic Lake BGC	*P. schreberi*	0.51	600	540	13.0	42	3.0	0.81	27	0.09		43	3	42	8566
Plastic Lake BGC	*P. schreberi*	0.47	710	590	108.0	49	16.0	0.80	28	0.09		49	3	35	11827
Plastic Lake	*P. schreberi*	0.51	810	662	12.1	70	5.0	1.00	23	0.11	0.33	66	2	36	12100
Plastic Lake BGC	*P. schreberi*	0.51	750	570	11.3	32	2.0	1.00	22	0.11		33	2	38	11557
Plastic Lake BGC	*P. schreberi*	0.68	680	550	15.2	55	3.0	1.19	23	0.11		39	3	41	8567
Plastic Lake BGC	*P. schreberi*	0.54	770	740	12.0	58	4.0	0.95	20	0.08		45	2	32	11826
Plastic Lake	*P. schreberi*	0.37	710	590	10.3	70	6.0	0.70	30	0.11	0.46	66	3	40	12225
Plastic Lake BGC	*P. schreberi*	0.49	740	460	11.5	30	2.0	0.90	27	0.10		40	2	41	11544
Plastic Lake BGC	*P. schreberi*	0.56	600	570	11.0	29	4.0	2.67	27	0.09		36	3	40	8568
Plastic Lake BGC	*P. schreberi*	0.57	720	540	10.4	48	30.0	0.80	21	0.02		41	2	38	11825
Port Severn	*C. mitis*	0.14	330	21	7.1	60	2.0	0.30	22	0.05		120	2	18	12119
Port Severn	*C. rangiferina*	0.17	240	55	5.8	40	1.0	0.40	11	0.04	0.13	50	1	13	12153
Port Severn	*C. rangiferina*	0.13	250	18	5.8	30	2.0	0.30	20	0.04		68	1	15	12212
Port Severn	*C. rangiferina*	0.14	280	63	5.2	30	1.0	0.50	13	0.03		57	1	18	12213
Port Severn	*P. schreberi*	0.36	700	340	7.8	100	6.0	0.90	27	0.08		80	2	28	12280
Port Severn	*P. schreberi*	0.41	600	294	7.4	80	2.0	0.70	15	0.10		49	1	16	12160
Pukaskwa	*C. mitis*	0.13	240	48	1.1	41	2.0	<0.1	9	0.03		65	2	14	11816
Pukaskwa	*C. rangiferina*	0.16	270	78	5.8	49	<1	0.50	10	0.04		60	2	17	11817
Pukaskwa	*P. schreberi*	0.34	1300	310	2.9	49	3.0	0.30	33	0.10		70	3	76	11818
Ramsey	*C. mitis*	0.16	420	47	4.2	50	3.0	0.40	9	0.02		130	2	15	12189
Ramsey	*C. mitis*	0.17	420	26	4.5	70	2.0	0.40	12	0.03		180	2	16	12151
Ramsey	*C. rangiferina*	0.16	350	30	3.7	60	2.0	0.50	10	0.03	0.06	22	2	14	12117
Ramsey	*C. rangiferina*	0.19	340	30	5.3	40	2.0	0.50	13	0.04		115	2	16	12163
Ramsey	*P. schreberi*	0.35	770	217	8.3	100	4.0	0.80	16	0.07		220	4	25	12167
Ramsey	*P. schreberi*	0.45	1250	172	7.6	100	8.0	0.90	18	0.10	0.20	390	5	37	12183
Remi Lake	*C. mitis*	0.19	380	44	7.1	90	1.0	0.80	11	0.03		73	1	18	12109
Remi Lake	*C. rangiferina*	0.17	330	79	4.8	60	<1	0.50	9	0.03	0.02	48	1	18	12146
Remi Lake	*P. schreberi*	0.49	940	470	8.9	110	3.0	1.40	20	0.10	0.20	87	2	70	12116
Remi Lake	*P. schreberi*	0.52	2350	370	10.4	200	3.0	1.00	17	0.10		280	5	50	12128
S. S. Marie	*C. mitis*	0.14	420	27	5.9	45	1.0	0.50	16	0.04		61	2	18	11524
S. S. Marie	*C. mitis*	0.16	380	24	5.7	40	<1	0.40	11	0.03		46	1	17	11521
S. S. Marie	*C. rangiferina*	0.16	390	25	6.0	32	<1	0.60	9	0.04		44	1	20	11525
S. S. Marie	*C. rangiferina*	0.14	410	40	6.1	28	<1	0.40	10	0.04		47	1	18	11526
S. S. Marie	*C. rangiferina*	0.17	400	38	6.5	38	<1	0.40	11	0.05		43	1	21	11510
S. S. Marie	*C. stellaris*	0.16	350	26	8.2	38	<1	0.50	12	0.06		52	1	26	11515
S. S. Marie	*P. schreberi*	0.39	1500	170	10.8	70	8.0	1.10	25	0.12		59	2	36	11559
S. S. Marie	*P. schreberi*	0.37	1300	130	6.8	62	3.0	0.70	22	0.08		56	2	51	11560
S. S. Marie	*P. schreberi*	0.35	1100	200	9.1	28	2.0	0.70	26	0.10		71	2	32	11545
Sauble	*C. mitis*	0.17	590	31	7.0	30	2.0	0.40	16	0.06		120	2	20	12203
Sauble	*C. mitis*	0.15	490	23	7.0	30	2.0	0.40	19	0.06		120	2	25	12208
Sauble	*C. rangiferina*	0.17	490	33	7.9	40	2.0	0.40	23	0.06	0.33	70	2	120	12180
Sauble	*C. rangiferina*	0.16	570	30	6.4	20	2.0	0.30	18	0.05		79	2	27	12215
Sauble	*P. schreberi*	0.44	6260	144	13.1	190	7.0	1.20	44	0.15	0.66	420	8	62	12105
Sauble	*P. schreberi*	0.36	7260	300	10.4	130	6.0	0.70	59	0.13		290	7	53	12197
Smokey Falls	*C. mitis*	0.16	740	32	4.2	52	2.0	0.36	5	0.02		210	5	19	11855
Smokey Falls	*C. mitis*	0.16	620	28	4.1	42	2.0	0.32	4	0.02		230	4	12	11856
Smokey Falls	*C. mitis*	0.16	780	35	4.4	48	3.0	0.38	4	0.02		190	4	17	11857
Smokey Falls	*C. rangiferina*	0.14	530	38	4.1	29	1.0	0.39	5	0.02		100	2	18	11860
Smokey Falls	*C. rangiferina*	0.15	550	33	4.5	31	2.0	0.39	5	0.02		100	2	21	11859
Smokey Falls	*C. rangiferina*	0.15	590	38	5.0	35	2.0	0.47	5	0.02		98	3	24	11858
Smokey Falls	*C. stellaris*	0.11	360	35	3.6	26	<1	0.42	3	0.01		49	1	15	11863
Smokey Falls	*C. stellaris*	0.11	340	36	3.6	27	1.0	0.43	3	0.02		52	1	16	11862
Smokey Falls	*C. stellaris*	0.11	380	39	3.7	32	1.0	0.37	3	0.01		65	2	14	11861
Smokey Falls	*E. mesomorpha*	0.32	1200	67	7.4	91	5.0	0.64	18	0.09		240	6	46	11866
Smokey Falls	*E. mesomorpha*	0.31	1100	54	7.6	100	4.0	0.55	21	0.09		240	7	75	11865
Smokey Falls	*E. mesomorpha*	0.29	1100	61	7.2	86	5.0	0.60	23	0.08		210	5	47	11864
Smokey Falls	*H. physodes*	0.35	780	59	7.7	58	2.0	0.70	20	0.08		110	3	55	11869
Smokey Falls	*H. physodes*	0.34	800	64	6.4	67	2.0	0.54	19	0.08		110	3	58	11868

	Species	K µg/g	Mg µg/g	Mn µg/g	N mg/g	Na µg/g	Ni µg/g	P mg/g	Pb µg/g	S %	Se µg/g	Ti µg/g	V µg/g	Zn µg/g	Sample Number
Smokey Falls	*H. physodes*	0.33	770	57	5.9	59	2.0	0.50	19	0.08		97	3	56	11867
Smokey Falls	*P. sulcata*	0.60	2600	240	5.5	110	6.0	1.55	21	0.09		340	12	89	11872
Smokey Falls	*P. sulcata*	0.55	2600	220	6.9	120	7.0	1.86	22	0.08		330	12	87	11871
Smokey Falls	*P. sulcata*	0.57	2800	250	6.5	88	6.0	1.85	25	0.08		300	10	95	11870
White River	*C. mitis*	0.34	580	86	6.1	47	1.0	0.60	13	0.04		64	2	32	11537
White River	*C. mitis*	0.20	330	44	4.6	32	<1	0.40	13	0.03		38	1	18	11535
White River	*C. mitis*	0.15	390	72	6.6	32	<1	0.70	13	0.05		52	1	61	11522
White River	*C. rangiferina*	0.32	510	130	7.2	38	1.0	0.60	17	0.06		56	1	35	11536
White River	*C. rangiferina*	0.16	410	110	7.0	30	<1	0.60	9	0.05		31	1	26	11512
White River	*C. rangiferina*	0.15	360	53	5.8	36	<1	0.50	11	0.04		44	1	19	11516
White River	*P. schreberi*	0.34	1000	260	10.9	42	2.0	1.00	19	0.09		60	2	43	11562
White River	*P. schreberi*	0.38	970	240	10.5	37	1.0	1.00	17	0.09		56	2	40	11543
White River	*P. schreberi*	0.36	950	230	9.7	60	2.0	0.90	18	0.10		68	2	42	11561
Whitney	*C. mitis*	0.21	450	69	5.4	20	1.0	0.60	10	0.04		54	1	38	12199
Whitney	*C. mitis*	0.13	240	47	5.0	20	1.0	0.40	10	0.03		83	1	22	12164
Whitney	*C. mitis*	0.14	310	63	5.3	30	1.0	0.40	15	0.03		92	2	26	12220
Whitney	*C. rangiferina*	0.17	360	62	5.4	30	1.0	0.50	13	0.04		56	1	31	12184
Whitney	*C. rangiferina*	0.28	460	89	7.1	30	2.0	1.00	15	0.06		92	1	37	12187
Whitney	*P. schreberi*	0.51	890	476	9.6	70	3.0	1.00	25	0.10		74	2	72	12113
Whitney	*P. schreberi*	0.53	810	605	8.2	60	2.0	1.00	26	0.10		79	2	48	12165
Whitney	*P. schreberi*	0.57	760	309	7.2	50	3.0	0.80	18	0.09		67	2	38	12170
Whitney	*P. schreberi*	0.59	1070	245	7.6	70	2.0	1.10	24	0.10		95	3	74	12195
Winisk	*Evernia/Ramalina*	0.23	880	28	7.5	320	1.0	0.80	14	0.08		80	2	28	11548
Winisk	*Evernia/Ramalina*	0.22	710	23	6.1	250	<1	0.70	11	0.06		70	1	23	11552
Winisk	*Evernia/Ramalina*	0.28	1400	46	5.0	430	2.0	0.80	18	0.10		167	3	34	11549
Winisk	*Evernia/Ramalina*	0.27	1200	32	7.1	360	2.0	0.80	18	0.10		140	3	32	11550
Winisk	*Evernia/Ramalina*	0.21	840	21	6.1	300	1.0	0.70	13	0.07		80	2	33	11551
Winisk	*H. physodes*	0.26	1500	88	6.1	330	2.0	0.80	17	0.08		132	3	41	11553
Winisk	*H. physodes*	0.30	1900	44	6.5	460	2.0	0.80	22	0.10		151	4	44	11546
Winisk	*H. physodes*	0.31	2200	61	7.1	410	3.0	0.80	26	0.10		137	5	48	11547
Winisk	*T. nitens*	0.50	1800	52	8.2	300	<1	1.20	3	0.05		18	1	52	11573
Winisk	*T. nitens*	0.46	2000	110	8.5	340	<1	1.30	3	0.06		20	1	11	11574

T = Time series sample
S = Survey sample
Special = only species present

W = Ground in Wiley mill
L = Ground under liquid nitrogen

Appendix B: Measurements of *Parmelia sulcata* thalli in BGC Permanent Quadrats

Quadrat	Thallus	Area mm^2	Tree
HL-1201	1	39.2	*Pinus strobus*
	2	21.8	*Pinus strobus*
	3	18.8	*Pinus strobus*
	4	10.1	*Pinus strobus*
	5	27.6	*Pinus strobus*
	6	87.2	*Pinus strobus*
	7	13.2	*Pinus strobus*
	8	238.0	*Pinus strobus*
	9	23.1	*Pinus strobus*
	10	8.7	*Pinus strobus*
	11	12.7	*Pinus strobus*
	12	96.6	*Pinus strobus*
	13	53.2	*Pinus strobus*
	14	549.0	*Pinus strobus*
	15	113.7	*Pinus strobus*
	16	60.9	*Pinus strobus*
	17	23.2	*Pinus strobus*
	18	22.6	*Pinus strobus*
	19	148.4	*Pinus strobus*
	20	300.5	*Pinus strobus*
	21	69.0	*Pinus strobus*
	22	125.3	*Pinus strobus*
	23	11.7	*Pinus strobus*
HL-1202	1	144.1	*Pinus strobus*
	2	86.5	*Pinus strobus*
	3	12.2	*Pinus strobus*
	4	22.4	*Pinus strobus*
	5	18.5	*Pinus strobus*
	6	449.9	*Pinus strobus*
	7	52.6	*Pinus strobus*
	8	129.9	*Pinus strobus*
	9	194.4	*Pinus strobus*
	10	33.8	*Pinus strobus*
	11	11.5	*Pinus strobus*
HL-1203	1	8.2	*Pinus strobus*
	2	3.7	*Pinus strobus*
	3	121.7	*Pinus strobus*
	4	30.9	*Pinus strobus*
	5	113.3	*Pinus strobus*
	6	129.2	*Pinus strobus*
	7	207.4	*Pinus strobus*
	8	32.0	*Pinus strobus*
HL-1204	1	176.6	*Pinus strobus*
	2	239.7	*Pinus strobus*
	3	1035.3	*Pinus strobus*
	4	282.2	*Pinus strobus*
	5	70.2	*Pinus strobus*
	6	324.9	*Pinus strobus*
	7	283.3	*Pinus strobus*
	8	23.4	*Pinus strobus*
	9	35.9	*Pinus strobus*
	10	116.2	*Pinus strobus*
	11	72.9	*Pinus strobus*
	12	272.8	*Pinus strobus*
	13	146.5	*Pinus strobus*
	14	105.0	*Pinus strobus*
	15	162.6	*Pinus strobus*
	16	28.2	*Pinus strobus*
	17	76.9	*Pinus strobus*
	18	96.1	*Pinus strobus*
	19	10.0	*Pinus strobus*
HL-1205	1	28.3	*Pinus strobus*
	2	50.2	*Pinus strobus*
	3	204.7	*Pinus strobus*
	4	35.9	*Pinus strobus*
	5	414.5	*Pinus strobus*
	6	141.0	*Pinus strobus*
	7	122.0	*Pinus strobus*
	8	83.6	*Pinus strobus*
	9	156.7	*Pinus strobus*
	10	39.4	*Pinus strobus*
	11	34.1	*Pinus strobus*
	12	149.3	*Pinus strobus*
	13	54.2	*Pinus strobus*
	14	23.7	*Pinus strobus*
	15	8.1	*Pinus strobus*
HL-1206	1	105.5	*Pinus strobus*
	2	60.2	*Pinus strobus*
	3	82.4	*Pinus strobus*
	4	457.6	*Pinus strobus*
	5	646.4	*Pinus strobus*
	6	25.4	*Pinus strobus*
	7	19.0	*Pinus strobus*
HL-1207	1	228.1	*Pinus strobus*
	2	14.7	*Pinus strobus*
HL-1208	1	259.1	*Pinus strobus*
	2	282.0	*Pinus strobus*
	3	15.7	*Pinus strobus*
	4	38.1	*Pinus strobus*
	5	132.6	*Pinus strobus*
	6	7.4	*Pinus strobus*
	7	58.0	*Pinus strobus*
	8	22.9	*Pinus strobus*
	9	73.5	*Pinus strobus*
	10	14.3	*Pinus strobus*
	11	15.4	*Pinus strobus*
	12	58.5	*Pinus strobus*
HL-1209	1	79.2	*Pinus strobus*
	2	45.5	*Pinus strobus*
	3	258.6	*Pinus strobus*
	4	225.8	*Pinus strobus*
	5	32.6	*Pinus strobus*
HL-1210	1	26.2	*Pinus strobus*
	2	66.2	*Pinus strobus*
	3	107.5	*Pinus strobus*
	4	13.2	*Pinus strobus*
	5	9.2	*Pinus strobus*
	6	51.6	*Pinus strobus*
	7	193.8	*Pinus strobus*
	8	84.9	*Pinus strobus*
	9	14.0	*Pinus strobus*
	10	26.6	*Pinus strobus*
	11	513.7	*Pinus strobus*
	12	197.2	*Pinus strobus*
	13	804.6	*Pinus strobus*
	14	64.0	*Pinus strobus*

Quadrat	Thallus	Area mm^2	Tree
	15	70.6	*Pinus strobus*
HL-1211	1	23.1	*Pinus strobus*
	2	41.8	*Pinus strobus*
	3	246.5	*Pinus strobus*
	4	49.8	*Pinus strobus*
	5	121.7	*Pinus strobus*
	6	21.1	*Pinus strobus*
	7	11.6	*Pinus strobus*
HL-1212	1	292.3	*Pinus strobus*
	2	20.5	*Pinus strobus*
	3	23.0	*Pinus strobus*
	4	87.7	*Pinus strobus*
	5	6.2	*Pinus strobus*
HL-1213	1	12.0	*Pinus strobus*
	2	23.7	*Pinus strobus*
	3	821.4	*Pinus strobus*
	4	9.3	*Pinus strobus*
	5	33.8	*Pinus strobus*
HL-1214	1	239.8	*Pinus strobus*
	2	1022.2	*Pinus strobus*
	3	121.6	*Pinus strobus*
	4	11.1	*Pinus strobus*
	5	37.6	*Pinus strobus*
HL-1220	1	441.0	*Pinus strobus*
	2	305.3	*Pinus strobus*
	3	469.7	*Pinus strobus*
	4	17.2	*Pinus strobus*
	5	74.5	*Pinus strobus*
	6	32.9	*Pinus strobus*
	7	71.1	*Pinus strobus*
	8	38.3	*Pinus strobus*
	9	206.5	*Pinus strobus*
	10	39.7	*Pinus strobus*
	11	82.3	*Pinus strobus*
	12	489.3	*Pinus strobus*
	13	45.6	*Pinus strobus*
	14	14.1	*Pinus strobus*
	15	19.7	*Pinus strobus*
	16	104.7	*Pinus strobus*
	17	41.1	*Pinus strobus*
	18	17.9	*Pinus strobus*
	19	46.0	*Pinus strobus*
HL-1222	1	51.5	*Abies balsamea*
	2	152.4	*Abies balsamea*
	3	101.2	*Abies balsamea*
	4	52.1	*Abies balsamea*
	5	114.9	*Abies balsamea*
	6	20.1	*Abies balsamea*
HL-1223	1	67.6	*Abies balsamea*
	2	53.8	*Abies balsamea*
	3	146.0	*Abies balsamea*
	4	21.3	*Abies balsamea*
	5	195.6	*Abies balsamea*
	6	91.5	*Abies balsamea*
	7	23.1	*Abies balsamea*
	8	50.3	*Abies balsamea*
	9	69.2	*Abies balsamea*
	10	88.4	*Abies balsamea*
	11	131.7	*Abies balsamea*
	12	1119.2	*Abies balsamea*
	13	179.9	*Abies balsamea*
	14	7.6	*Abies balsamea*

Quadrat	Thallus	Area mm^2	Tree
HL-1224	1	176.2	*Abies balsamea*
	2	3427.0	*Abies balsamea*
	3	256.1	*Abies balsamea*
	4	431.6	*Abies balsamea*
HL-1225	1	37.9	*Abies balsamea*
	2	203.4	*Abies balsamea*
	3	13.5	*Abies balsamea*
	4	8.3	*Abies balsamea*
	5	34.3	*Abies balsamea*
	6	34.0	*Abies balsamea*
	7	11.6	*Abies balsamea*
	8	36.1	*Abies balsamea*
	9	51.3	*Abies balsamea*
	10	12.7	*Abies balsamea*
	11	561.0	*Abies balsamea*
	12	498.6	*Abies balsamea*
	13	1724.2	*Abies balsamea*
	14	56.5	*Abies balsamea*
	15	31.5	*Abies balsamea*
	16	6.8	*Abies balsamea*
	17	13.5	*Abies balsamea*
	18	31.8	*Abies balsamea*
	19	51.1	*Abies balsamea*
	20	96.4	*Abies balsamea*
HL-1226	1	163.3	*Abies balsamea*
	2	53.2	*Abies balsamea*
	3	19.9	*Abies balsamea*
	4	16.6	*Abies balsamea*
	5	988.7	*Abies balsamea*
	6	37.0	*Abies balsamea*
HL-1227	1	774.1	*Abies balsamea*
	2	35.7	*Abies balsamea*
	3	351.1	*Abies balsamea*
	4	471.1	*Abies balsamea*
	5	98.1	*Abies balsamea*
	6	199.7	*Abies balsamea*
	7	96.9	*Abies balsamea*
	8	2032.8	*Abies balsamea*
	9	144.2	*Abies balsamea*
HL-1228	1	44.0	*Abies balsamea*
	2	25.2	*Abies balsamea*
	3	63.2	*Abies balsamea*
	4	1090.7	*Abies balsamea*
	5	52.0	*Abies balsamea*
	6	43.9	*Abies balsamea*
	7	185.1	*Abies balsamea*
HL-1229	1	147.8	*Abies balsamea*
	2	96.3	*Abies balsamea*
	3	207.0	*Abies balsamea*
	4	13.3	*Abies balsamea*
	5	722.4	*Abies balsamea*
	6	516.3	*Abies balsamea*
	7	176.0	*Abies balsamea*
	8	6.7	*Abies balsamea*
	9	116.8	*Abies balsamea*
	10	462.6	*Abies balsamea*
	11	32.5	*Abies balsamea*
	12	145.6	*Abies balsamea*
HL-1230	1	1381.8	*Abies balsamea*
	2	2117.4	*Abies balsamea*
	3	3652.5	*Abies balsamea*
HL-1231	1	101.0	*Abies balsamea*

Quadrat	Thallus	Area mm^2	Tree
	2	219.2	*Abies balsamea*
	3	116.1	*Abies balsamea*
	4	56.2	*Abies balsamea*
	5	49.2	*Abies balsamea*
	6	23.0	*Abies balsamea*
	7	166.5	*Abies balsamea*
	8	36.6	*Abies balsamea*
	9	125.2	*Abies balsamea*
	10	303.0	*Abies balsamea*
	11	136.5	*Abies balsamea*
	12	243.7	*Abies balsamea*
	13	187.9	*Abies balsamea*
HL-1232	1	389.9	*Abies balsamea*
	2	2480.4	*Abies balsamea*
	3	12.0	*Abies balsamea*
	4	1114.5	*Abies balsamea*
	5	668.2	*Abies balsamea*
	6	111.5	*Abies balsamea*
HL-1233	1	55.2	*Abies balsamea*
	2	670.5	*Abies balsamea*
	3	31.9	*Abies balsamea*
	4	80.8	*Abies balsamea*
	5	22.0	*Abies balsamea*
	6	100.6	*Abies balsamea*
	7	39.4	*Abies balsamea*
HL-1234	1	337.2	*Abies balsamea*
	2	104.5	*Abies balsamea*
	3	2856.0	*Abies balsamea*
	4	113.0	*Abies balsamea*
	5	316.0	*Abies balsamea*
	6	97.2	*Abies balsamea*
HL-1235	1	41.8	*Abies balsamea*
	2	73.5	*Abies balsamea*
	3	207.6	*Abies balsamea*
	4	31.6	*Abies balsamea*
	5	35.5	*Abies balsamea*
	6	24.1	*Abies balsamea*
	7	5.8	*Abies balsamea*
	8	253.6	*Abies balsamea*
	9	292.4	*Abies balsamea*
	10	98.4	*Abies balsamea*
	11	34.4	*Abies balsamea*
HL-1236	1	472.6	*Abies balsamea*
	2	173.6	*Abies balsamea*
	3	146.7	*Abies balsamea*
	4	223.6	*Abies balsamea*
	5	3012.1	*Abies balsamea*
	6	117.7	*Abies balsamea*
	7	58.7	*Abies balsamea*
	8	681.4	*Abies balsamea*
	9	144.4	*Abies balsamea*
	10	203.8	*Abies balsamea*
HL-1237	1	132.9	*Abies balsamea*
	2	22.5	*Abies balsamea*
	3	94.7	*Abies balsamea*
	4	110.9	*Abies balsamea*
	5	240.0	*Abies balsamea*
	6	568.8	*Abies balsamea*
	7	331.2	*Abies balsamea*
	8	33.9	*Abies balsamea*
	9	8.1	*Abies balsamea*
	10	36.9	*Abies balsamea*

Quadrat	Thallus	Area mm^2	Tree
	11	130.8	*Abies balsamea*
	12	53.0	*Abies balsamea*
	13	14.0	*Abies balsamea*
	14	363.5	*Abies balsamea*
	15	19.1	*Abies balsamea*
	16	69.5	*Abies balsamea*
	17	32.1	*Abies balsamea*
	18	69.7	*Abies balsamea*
HL-1238	1	15.3	*Abies balsamea*
	2	57.7	*Abies balsamea*
	3	46.0	*Abies balsamea*
	4	17.2	*Abies balsamea*
	5	68.3	*Abies balsamea*
	6	23.8	*Abies balsamea*
	7	578.3	*Abies balsamea*
	8	153.1	*Abies balsamea*
	9	130.1	*Abies balsamea*
	10	49.3	*Abies balsamea*
	11	249.9	*Abies balsamea*
	12	49.2	*Abies balsamea*
	13	20.5	*Abies balsamea*
HL-1239	1	160.4	*Abies balsamea*
	2	36.0	*Abies balsamea*
	3	7.8	*Abies balsamea*
	4	58.4	*Abies balsamea*
	5	302.6	*Abies balsamea*
	6	18.0	*Abies balsamea*
	7	38.6	*Abies balsamea*
	8	74.2	*Abies balsamea*
	9	1165.0	*Abies balsamea*
	10	5.4	*Abies balsamea*
	11	18.1	*Abies balsamea*
	12	44.8	*Abies balsamea*
	13	40.2	*Abies balsamea*
	14	7.2	*Abies balsamea*
HL-1240	1	17.0	*Abies balsamea*
	2	570.6	*Abies balsamea*
	3	39.6	*Abies balsamea*
	4	22.0	*Abies balsamea*
	5	4.4	*Abies balsamea*
	6	136.9	*Abies balsamea*
	7	20.8	*Abies balsamea*
	8	17.5	*Abies balsamea*
	9	48.5	*Abies balsamea*
	10	2116.2	*Abies balsamea*
	11	143.6	*Abies balsamea*
	12	51.8	*Abies balsamea*
HL-1241	1	39.3	*Picea mariana*
	2	23.7	*Picea mariana*
	3	1111.0	*Picea mariana*
	4	33.6	*Picea mariana*
	5	26.9	*Picea mariana*
HL-1242	1	52.4	*Picea glauca*
	2	329.6	*Picea glauca*
	3	87.0	*Picea glauca*
HL-1243	1	14.6	*Picea glauca*
	2	6.8	*Picea glauca*
	3	11.2	*Picea glauca*
	4	21.3	*Picea glauca*
	5	14.8	*Picea glauca*
	6	25.1	*Picea glauca*
	7	105.0	*Picea glauca*

Quadrat	Thallus	Area mm^2	Tree
	8	32.1	*Picea glauca*
	9	185.6	*Picea glauca*
	10	74.1	*Picea glauca*
	11	38.8	*Picea glauca*
	12	73.5	*Picea glauca*
	13	10.0	*Picea glauca*
	14	18.9	*Picea glauca*
HL-1244	1	20.4	*Picea glauca*
	2	36.0	*Picea glauca*
	3	23.4	*Picea glauca*
	4	19.1	*Picea glauca*
	5	44.4	*Picea glauca*
	6	7.6	*Picea glauca*
	7	7.2	*Picea glauca*
	8	34.2	*Picea glauca*
	9	9.3	*Picea glauca*
	10	17.0	*Picea glauca*
	11	21.7	*Picea glauca*
	12	141.3	*Picea glauca*
	13	6.9	*Picea glauca*
	14	10.6	*Picea glauca*
	15	24.8	*Picea glauca*
	16	6.9	*Picea glauca*
	17	19.1	*Picea glauca*
	18	5.5	*Picea glauca*
	19	16.2	*Picea glauca*
HL-1245	1	83.5	*Picea glauca*
	2	39.9	*Picea glauca*
	3	98.3	*Picea glauca*
	4	836.1	*Picea glauca*
	5	326.2	*Picea glauca*
	6	163.0	*Picea glauca*
	7	10.7	*Picea glauca*
	8	8.9	*Picea glauca*
HL-1246	1	18.9	*Picea glauca*
	2	36.3	*Picea glauca*
	3	16.7	*Picea glauca*
	4	28.6	*Picea glauca*
	5	13.5	*Picea glauca*
	6	6.5	*Picea glauca*
	7	6.8	*Picea glauca*
	8	43.7	*Picea glauca*
	9	301.1	*Picea glauca*
	10	112.6	*Picea glauca*
	11	144.5	*Picea glauca*
	12	66.3	*Picea glauca*
	13	237.6	*Picea glauca*
	14	84.8	*Picea glauca*
HL-1247	1	50.4	*Picea glauca*
	2	30.5	*Picea glauca*
	3	185.0	*Picea glauca*
	4	394.2	*Picea glauca*
	5	81.6	*Picea glauca*
	6	77.6	*Picea glauca*
	7	86.2	*Picea glauca*
	8	22.2	*Picea glauca*
	9	30.6	*Picea glauca*
	10	104.8	*Picea glauca*
	11	62.9	*Picea glauca*
	12	60.6	*Picea glauca*
	13	19.1	*Picea glauca*
	14	53.8	*Picea glauca*

Quadrat	Thallus	Area mm^2	Tree
	15	11.7	*Picea glauca*
	16	104.5	*Picea glauca*
	17	36.0	*Picea glauca*
	18	98.7	*Picea glauca*
HL-1248	1	28.2	*Picea glauca*
	2	1459.5	*Picea glauca*
	3	27.0	*Picea glauca*
	4	550.7	*Picea glauca*
	5	18.0	*Picea glauca*
	6	61.8	*Picea glauca*
	7	492.7	*Picea glauca*
	8	13.7	*Picea glauca*
	9	7.8	*Picea glauca*
	10	565.1	*Picea glauca*
	11	378.4	*Picea glauca*
	12	6.5	*Picea glauca*
	13	60.0	*Picea glauca*
	14	32.0	*Picea glauca*
	15	85.5	*Picea glauca*
	16	94.8	*Picea glauca*
	17	35.1	*Picea glauca*
	18	6.9	*Picea glauca*
HL-1249	1	23.8	*Picea glauca*
	2	974.1	*Picea glauca*
	3	25.6	*Picea glauca*
	4	21.0	*Picea glauca*
	5	95.1	*Picea glauca*
	6	177.2	*Picea glauca*
	7	21.9	*Picea glauca*
	8	301.0	*Picea glauca*
	9	23.1	*Picea glauca*
	10	10.1	*Picea glauca*
HL-1250	1	18.5	*Picea glauca*
	2	8.8	*Picea glauca*
	3	8.4	*Picea glauca*
	4	302.3	*Picea glauca*
	5	315.3	*Picea glauca*
	6	11.3	*Picea glauca*
	7	9.6	*Picea glauca*
	8	5.4	*Picea glauca*
	9	25.7	*Picea glauca*
	10	19.2	*Picea glauca*
	11	11.6	*Picea glauca*
HL-1251	1	78.1	*Picea glauca*
	2	821.0	*Picea glauca*
	3	119.3	*Picea glauca*
	4	92.8	*Picea glauca*
	5	5.4	*Picea glauca*
	6	12.5	*Picea glauca*
	7	15.1	*Picea glauca*
	8	18.2	*Picea glauca*
	9	77.5	*Picea glauca*
	10	87.7	*Picea glauca*
	11	28.6	*Picea glauca*
	12	41.4	*Picea glauca*
	13	143.0	*Picea glauca*
	14	29.9	*Picea glauca*
	15	6.5	*Picea glauca*
	16	61.3	*Picea glauca*
	17	65.5	*Picea glauca*
	18	34.3	*Picea glauca*
	19	42.5	*Picea glauca*

Quadrat	Thallus	Area mm^2	Tree
	20	73.2	*Picea glauca*
	21	6.6	*Picea glauca*
	22	13.8	*Picea glauca*
	23	21.1	*Picea glauca*
	24	42.5	*Picea glauca*
	25	580.7	*Picea glauca*
	26	15.1	*Picea glauca*
	27	69.8	*Picea glauca*
	28	119.3	*Picea glauca*
	29	103.9	*Picea glauca*
	30	38.0	*Picea glauca*
	31	24.1	*Picea glauca*
	32	26.9	*Picea glauca*
	33	209.5	*Picea glauca*
HL-1252	1	275.9	*Picea glauca*
	2	51.2	*Picea glauca*
	3	846.6	*Picea glauca*
	4	6.4	*Picea glauca*
	5	37.6	*Picea glauca*
	6	86.1	*Picea glauca*
	7	3035.4	*Picea glauca*
	8	66.5	*Picea glauca*
	9	21.5	*Picea glauca*
HL-1253	1	288.1	*Picea glauca*
	2	1437.4	*Picea glauca*
	3	47.5	*Picea glauca*
	4	18.5	*Picea glauca*
	5	82.0	*Picea glauca*
	6	59.9	*Picea glauca*
	7	25.2	*Picea glauca*
	8	2304.7	*Picea glauca*
	9	392.6	*Picea glauca*
	10	28.4	*Picea glauca*
	11	59.3	*Picea glauca*
	12	27.0	*Picea glauca*
HL-1254	1	111.4	*Picea glauca*
	2	7.7	*Picea glauca*
	3	167.1	*Picea glauca*
	4	122.5	*Picea glauca*
	5	525.6	*Picea glauca*
	6	130.7	*Picea glauca*
	7	196.0	*Picea glauca*
	8	27.1	*Picea glauca*
	9	86.6	*Picea glauca*
	10	314.7	*Picea glauca*
	11	54.6	*Picea glauca*
	12	48.9	*Picea glauca*
	13	51.7	*Picea glauca*
	14	333.3	*Picea glauca*
	15	2571.3	*Picea glauca*
	16	104.8	*Picea glauca*
	17	111.9	*Picea glauca*
	18	93.4	*Picea glauca*
HL-1255	1	42.1	*Picea glauca*
	2	141.7	*Picea glauca*
	3	148.9	*Picea glauca*
	4	103.9	*Picea glauca*
	5	802.4	*Picea glauca*
	6	1395.5	*Picea glauca*
	7	4222.5	*Picea glauca*
	8	148.8	*Picea glauca*
HL-1256	1	35.2	*Picea glauca*

Quadrat	Thallus	Area mm^2	Tree
	2	24.0	*Picea glauca*
	3	56.8	*Picea glauca*
	4	9.8	*Picea glauca*
	5	41.4	*Picea glauca*
	6	124.1	*Picea glauca*
	7	373.6	*Picea glauca*
	8	25.3	*Picea glauca*
	9	2090.1	*Picea glauca*
	10	205.8	*Picea glauca*
	11	256.1	*Picea glauca*
	12	29.5	*Picea glauca*
	13	115.8	*Picea glauca*
	14	19.8	*Picea glauca*
	15	42.2	*Picea glauca*
	16	82.3	*Picea glauca*
	17	14.7	*Picea glauca*
	18	25.4	*Picea glauca*
	19	55.4	*Picea glauca*
HL-1257	1	114.8	*Picea glauca*
	2	78.7	*Picea glauca*
	3	21.9	*Picea glauca*
	4	55.5	*Picea glauca*
	5	542.3	*Picea glauca*
	6	79.2	*Picea glauca*
	7	30.5	*Picea glauca*
	8	22.2	*Picea glauca*
	9	42.9	*Picea glauca*
	10	565.5	*Picea glauca*
	11	1500.3	*Picea glauca*
	12	83.7	*Picea glauca*
	13	55.3	*Picea glauca*
	14	325.7	*Picea glauca*
	15	54.2	*Picea glauca*
	16	47.4	*Picea glauca*
	17	191.4	*Picea glauca*
	18	307.9	*Picea glauca*
	19	568.2	*Picea glauca*
	20	67.8	*Picea glauca*
HL-1259	1	15.6	*Picea glauca*
	2	98.6	*Picea glauca*
	3	927.6	*Picea glauca*
	4	64.9	*Picea glauca*
	5	316.8	*Picea glauca*
	6	174.4	*Picea glauca*
	7	342.6	*Picea glauca*
	8	36.9	*Picea glauca*
	9	61.5	*Picea glauca*
	10	105.1	*Picea glauca*
	11	1420.1	*Picea glauca*
HL-1261	1	311.5	*Picea glauca*
	2	28.1	*Picea glauca*
	3	27.0	*Picea glauca*
	4	22.1	*Picea glauca*
	5	80.7	*Picea glauca*
	6	55.0	*Picea glauca*
	7	136.2	*Picea glauca*
	8	13.4	*Picea glauca*
	9	117.2	*Picea glauca*
HF-1271		0.0	*Pinus strobus*
HF-1272		0.0	*Pinus strobus*
HF-1273		0.0	*Pinus strobus*
HF-1274		0.0	*Pinus strobus*

Quadrat	Thallus	Area mm^2	Tree
HF-1275		0.0	*Pinus strobus*
HF-1276		0.0	*Pinus strobus*
HF-1277		0.0	*Pinus strobus*
HF-1278		0.0	*Pinus strobus*
HF-1279		0.0	*Pinus strobus*
HF-1280		0.0	*Pinus strobus*
HF-1281		0.0	*Pinus strobus*
HF-1282		0.0	*Pinus strobus*
HF-1283		0.0	*Pinus strobus*
HF-1284		0.0	*Pinus strobus*
HF-1285		0.0	*Pinus strobus*
HF-1286		0.0	*Pinus strobus*
HF-1287		0.0	*Pinus strobus*
HF-1288		0.0	*Pinus strobus*
HF-1290		0.0	*Pinus strobus*
HF-1291	1	127.5	*Populus tremuloides*
	2	21.9	*Populus tremuloides*
	3	132.0	*Populus tremuloides*
	4	21.9	*Populus tremuloides*
	5	15.1	*Populus tremuloides*
	6	14.5	*Populus tremuloides*
	7	13.2	*Populus tremuloides*
	8	27.5	*Populus tremuloides*
	9	53.4	*Populus tremuloides*
	10	51.2	*Populus tremuloides*
	11	23.6	*Populus tremuloides*
	12	20.3	*Populus tremuloides*
	13	32.2	*Populus tremuloides*
	14	25.7	*Populus tremuloides*
	15	18.2	*Populus tremuloides*
	16	16.0	*Populus tremuloides*
	17	18.3	*Populus tremuloides*
	18	11.4	*Populus tremuloides*
	19	8.7	*Populus tremuloides*
	20	9.5	*Populus tremuloides*
	21	8.4	*Populus tremuloides*
	22	10.6	*Populus tremuloides*
	23	16.7	*Populus tremuloides*
HF-1293	1	183.5	*Populus tremuloides*
	2	46.1	*Populus tremuloides*
	3	47.0	*Populus tremuloides*
	4	22.0	*Populus tremuloides*
	5	46.5	*Populus tremuloides*
	6	106.9	*Populus tremuloides*
	7	30.6	*Populus tremuloides*
	8	28.2	*Populus tremuloides*
HF-1294	1	82.7	*Populus tremuloides*
	2	61.5	*Populus tremuloides*
	3	69.2	*Populus tremuloides*
	4	55.5	*Populus tremuloides*
	5	47.2	*Populus tremuloides*
	6	15.5	*Populus tremuloides*
	7	22.4	*Populus tremuloides*
	8	23.8	*Populus tremuloides*
	9	19.7	*Populus tremuloides*
	10	12.4	*Populus tremuloides*
	11	18.4	*Populus tremuloides*
HF-1295		5.2	*Populus tremuloides*
HF-1296	1	50.7	*Populus tremuloides*
	2	14.4	*Populus tremuloides*
	3	26.4	*Populus tremuloides*
	4	24.4	*Populus tremuloides*
	5	13.2	*Populus tremuloides*
	6	8.0	*Populus tremuloides*
	7	13.2	*Populus tremuloides*
	8	9.9	*Populus tremuloides*
	9	9.0	*Populus tremuloides*
	10	8.2	*Populus tremuloides*
HF-1297		0.0	*Populus tremuloides*
HF-1298	1	148.2	*Populus tremuloides*
	2	134.5	*Populus tremuloides*
	3	102.2	*Populus tremuloides*
	4	28.5	*Populus tremuloides*
	5	14.7	*Populus tremuloides*
	6	24.1	*Populus tremuloides*
	7	40.3	*Populus tremuloides*
	8	31.5	*Populus tremuloides*
	9	14.6	*Populus tremuloides*
	10	16.0	*Populus tremuloides*
	11	13.2	*Populus tremuloides*
	12	8.8	*Populus tremuloides*
	13	8.3	*Populus tremuloides*
	14	5.4	*Populus tremuloides*
	15	5.3	*Populus tremuloides*
	16	4.0	*Populus tremuloides*
	17	6.3	*Populus tremuloides*
	18	4.2	*Populus tremuloides*
HF-1299	1	643.0	*Populus tremuloides*
	2	81.3	*Populus tremuloides*
	3	20.6	*Populus tremuloides*
	4	16.9	*Populus tremuloides*
	5	43.9	*Populus tremuloides*
	6	12.6	*Populus tremuloides*
	7	7.9	*Populus tremuloides*
	8	4.4	*Populus tremuloides*
	9	4.9	*Populus tremuloides*
HF-1300	1	867.5	*Populus tremuloides*
	2	87.4	*Populus tremuloides*
	3	35.0	*Populus tremuloides*
	4	26.8	*Populus tremuloides*
	5	16.0	*Populus tremuloides*
	6	6.2	*Populus tremuloides*
	7	3.6	*Populus tremuloides*
HF-1301	1	21.7	*Populus tremuloides*
	2	12.1	*Populus tremuloides*
	3	5.4	*Populus tremuloides*
	4	2.9	*Populus tremuloides*
HF-1302	1	566.5	*Populus tremuloides*
	2	328.7	*Populus tremuloides*
	3	350.0	*Populus tremuloides*
	4	61.5	*Populus tremuloides*
	5	68.9	*Populus tremuloides*
	6	25.8	*Populus tremuloides*
	7	56.9	*Populus tremuloides*
	8	16.6	*Populus tremuloides*
	9	11.2	*Populus tremuloides*
	10	5.1	*Populus tremuloides*
	11	7.5	*Populus tremuloides*
	12	51.2	*Populus tremuloides*
	13	54.4	*Populus tremuloides*
HF-1303	1	356.8	*Populus tremuloides*
	2	289.4	*Populus tremuloides*
	3	392.4	*Populus tremuloides*
	4	812.0	*Populus tremuloides*

Quadrat	Thallus	Area mm^2	Tree
	5	121.9	*Populus tremuloides*
	6	38.5	*Populus tremuloides*
	7	119.3	*Populus tremuloides*
	8	90.0	*Populus tremuloides*
	9	19.5	*Populus tremuloides*
	10	14.2	*Populus tremuloides*
	11	10.2	*Populus tremuloides*
	12	2.0	*Populus tremuloides*
	13	7.1	*Populus tremuloides*
	14	17.7	*Populus tremuloides*
	15	13.0	*Populus tremuloides*
	16	6.7	*Populus tremuloides*
	17	31.2	*Populus tremuloides*
	18	7.4	*Populus tremuloides*
	19	19.2	*Populus tremuloides*
	20	7.2	*Populus tremuloides*
	21	5.2	*Populus tremuloides*
	22	3.8	*Populus tremuloides*
	23	25.5	*Populus tremuloides*
	24	6.2	*Populus tremuloides*
	25	4.6	*Populus tremuloides*
	26	17.1	*Populus tremuloides*
	27	6.4	*Populus tremuloides*
	28	12.8	*Populus tremuloides*
	29	5.0	*Populus tremuloides*
	30	28.6	*Populus tremuloides*
	31	24.5	*Populus tremuloides*
	32	1.8	*Populus tremuloides*
	33	5.2	*Populus tremuloides*
	34	12.3	*Populus tremuloides*
	35	3.4	*Populus tremuloides*
	36	13.6	*Populus tremuloides*
	37	3.8	*Populus tremuloides*
	38	8.3	*Populus tremuloides*
	39	10.9	*Populus tremuloides*
	40	8.0	*Populus tremuloides*
	41	8.9	*Populus tremuloides*
	42	4.7	*Populus tremuloides*
	43	3.2	*Populus tremuloides*
	44	3.1	*Populus tremuloides*
	45	4.2	*Populus tremuloides*
	46	8.9	*Populus tremuloides*
	47	6.1	*Populus tremuloides*
	48	5.6	*Populus tremuloides*
	49	3.8	*Populus tremuloides*
	50	3.3	*Populus tremuloides*
	51	4.6	*Populus tremuloides*
	52	23.3	*Populus tremuloides*
	53	2.1	*Populus tremuloides*
	54	4.5	*Populus tremuloides*
	55	2.7	*Populus tremuloides*
	56	18.8	*Populus tremuloides*
HF-1304	1	209.6	*Populus tremuloides*
	2	389.1	*Populus tremuloides*
	3	225.9	*Populus tremuloides*
	4	61.4	*Populus tremuloides*
	5	53.7	*Populus tremuloides*
	6	65.4	*Populus tremuloides*
	7	37.4	*Populus tremuloides*
	8	26.5	*Populus tremuloides*
	9	40.8	*Populus tremuloides*
	10	39.2	*Populus tremuloides*

Quadrat	Thallus	Area mm^2	Tree
	11	46.9	*Populus tremuloides*
	12	97.3	*Populus tremuloides*
	13	7.0	*Populus tremuloides*
	14	5.5	*Populus tremuloides*
	15	1.6	*Populus tremuloides*
	16	11.3	*Populus tremuloides*
	17	3.0	*Populus tremuloides*
	18	3.4	*Populus tremuloides*
	19	5.9	*Populus tremuloides*
	20	9.8	*Populus tremuloides*
	21	3.8	*Populus tremuloides*
	22	1.8	*Populus tremuloides*
	23	4.7	*Populus tremuloides*
	24	1.9	*Populus tremuloides*
	25	16.7	*Populus tremuloides*
	26	5.3	*Populus tremuloides*
	27	8.5	*Populus tremuloides*
	28	12.3	*Populus tremuloides*
	29	18.5	*Populus tremuloides*
	30	2.0	*Populus tremuloides*
	31	3.4	*Populus tremuloides*
	32	1.5	*Populus tremuloides*
	33	12.0	*Populus tremuloides*
	34	8.3	*Populus tremuloides*
	35	4.1	*Populus tremuloides*
	36	6.3	*Populus tremuloides*
	37	4.0	*Populus tremuloides*
	38	7.2	*Populus tremuloides*
	39	19.7	*Populus tremuloides*
	40	11.0	*Populus tremuloides*
	41	5.8	*Populus tremuloides*
	42	3.0	*Populus tremuloides*
	43	3.9	*Populus tremuloides*
	44	5.9	*Populus tremuloides*
	45	24.6	*Populus tremuloides*
	46	8.0	*Populus tremuloides*
	47	52.7	*Populus tremuloides*
	48	10.5	*Populus tremuloides*
HF-1305	1	3.4	*Populus tremuloides*
	2	3.3	*Populus tremuloides*
	3	3.9	*Populus tremuloides*
	4	1.5	*Populus tremuloides*
HF-1306	1	43.3	*Populus tremuloides*
	2	7.3	*Populus tremuloides*
	3	2.2	*Populus tremuloides*
	4	6.2	*Populus tremuloides*
	5	4.1	*Populus tremuloides*
	6	14.8	*Populus tremuloides*
	7	4.2	*Populus tremuloides*
	8	2.6	*Populus tremuloides*
	9	3.8	*Populus tremuloides*
HF-1307	1	663.8	*Populus tremuloides*
	2	537.9	*Populus tremuloides*
	3	199.4	*Populus tremuloides*
	4	137.1	*Populus tremuloides*
	5	79.6	*Populus tremuloides*
	6	148.6	*Populus tremuloides*
	7	41.4	*Populus tremuloides*
	8	33.7	*Populus tremuloides*
	9	16.0	*Populus tremuloides*
	10	9.4	*Populus tremuloides*
	11	12.4	*Populus tremuloides*

Quadrat	Thallus	Area mm^2	Tree
	12	16.9	*Populus tremuloides*
	13	8.7	*Populus tremuloides*
	14	21.1	*Populus tremuloides*
	15	48.7	*Populus tremuloides*
	16	3.6	*Populus tremuloides*
	17	4.7	*Populus tremuloides*
	18	6.2	*Populus tremuloides*
	19	24.4	*Populus tremuloides*
	20	6.2	*Populus tremuloides*
	21	8.6	*Populus tremuloides*
HF-1308	1	155.8	*Populus tremuloides*
	2	92.7	*Populus tremuloides*
	3	14.1	*Populus tremuloides*
	4	3.7	*Populus tremuloides*
	5	2.6	*Populus tremuloides*
	6	2.7	*Populus tremuloides*
	7	5.9	*Populus tremuloides*
	8	6.7	*Populus tremuloides*
	9	10.9	*Populus tremuloides*
	10	2.8	*Populus tremuloides*
	11	19.3	*Populus tremuloides*
PL-1309	1	285.1	*Populus tremuloides*
	2	208.6	*Populus tremuloides*
	3	22.2	*Populus tremuloides*
	4	13.1	*Populus tremuloides*
	5	9.2	*Populus tremuloides*
	6	16.4	*Populus tremuloides*
	7	8.0	*Populus tremuloides*
	8	5.2	*Populus tremuloides*
	9	17.5	*Populus tremuloides*
	10	9.0	*Populus tremuloides*
PL-1311	1	189.5	*Quercus rubra*
	2	20.1	*Quercus rubra*
	3	10.0	*Quercus rubra*
	4	59.6	*Quercus rubra*
PL-1312	1	12.5	*Quercus rubra*
	2	22.4	*Quercus rubra*
	3	7.9	*Quercus rubra*
	4	12.6	*Quercus rubra*
	5	4.5	*Quercus rubra*
	6	6.3	*Quercus rubra*
	7	5.7	*Quercus rubra*
	8	105.2	*Quercus rubra*
	9	4.4	*Quercus rubra*
	10	2.6	*Quercus rubra*
	11	11.4	*Quercus rubra*
	12	10.4	*Quercus rubra*
	13	5.9	*Quercus rubra*
	14	8.8	*Quercus rubra*
	15	45.7	*Quercus rubra*
	16	42.3	*Quercus rubra*
PL-1313	1	144.5	*Quercus rubra*
	2	57.2	*Quercus rubra*
	3	360.1	*Quercus rubra*
	4	337.4	*Quercus rubra*
	5	45.8	*Quercus rubra*
	6	33.6	*Quercus rubra*
	7	10.7	*Quercus rubra*
	8	8.2	*Quercus rubra*
PL-1314	gc		*Quercus rubra*
PL-1315	1	50.6	*Quercus rubra*
	2	12.1	*Quercus rubra*

Quadrat	Thallus	Area mm^2	Tree
	3	127.3	*Quercus rubra*
	4	18.9	*Quercus rubra*
	5	18.0	*Quercus rubra*
	6	11.8	*Quercus rubra*
	7	5.8	*Quercus rubra*
	8	20.3	*Quercus rubra*
	9	39.8	*Quercus rubra*
	10	16.7	*Quercus rubra*
	11	28.3	*Quercus rubra*
	12	9.2	*Quercus rubra*
	13	10.7	*Quercus rubra*
	14	18.2	*Quercus rubra*
	15	13.2	*Quercus rubra*
	16	24.1	*Quercus rubra*
	17	9.9	*Quercus rubra*
	18	5.5	*Quercus rubra*
	19	12.1	*Quercus rubra*
	20	5.6	*Quercus rubra*
PL-1316	1	8.7	*Quercus rubra*
	2	5.4	*Quercus rubra*
	3	56.2	*Quercus rubra*
	4	95.6	*Quercus rubra*
	5	101.5	*Quercus rubra*
	6	12.4	*Quercus rubra*
	7	16.3	*Quercus rubra*
	8	26.2	*Quercus rubra*
	9	7.6	*Quercus rubra*
	10	15.3	*Quercus rubra*
	11	12.9	*Quercus rubra*
	12	14.5	*Quercus rubra*
	13	18.6	*Quercus rubra*
	14	287.0	*Quercus rubra*
	15	16.6	*Quercus rubra*
	16	244.9	*Quercus rubra*
	17	141.5	*Quercus rubra*
	18	188.1	*Quercus rubra*
	19	15.9	*Quercus rubra*
	20	10.4	*Quercus rubra*
	21	9.6	*Quercus rubra*
	22	12.0	*Quercus rubra*
PL-1317	1	11.4	*Quercus rubra*
	2	26.9	*Quercus rubra*
	3	91.6	*Quercus rubra*
	4	32.7	*Quercus rubra*
PL-1318	1	35.4	*Quercus rubra*
	2	20.4	*Quercus rubra*
	3	139.4	*Quercus rubra*
	4	26.5	*Quercus rubra*
	5	12.8	*Quercus rubra*
	6	11.5	*Quercus rubra*
	7	10.0	*Quercus rubra*
	8	12.7	*Quercus rubra*
PL-1319	1	2444.9	*Quercus rubra*
	2	32.8	*Quercus rubra*
	3	38.7	*Quercus rubra*
	4	136.9	*Quercus rubra*
	5	94.5	*Quercus rubra*
	6	13.9	*Quercus rubra*
	7	24.0	*Quercus rubra*
	8	28.1	*Quercus rubra*
	9	29.4	*Quercus rubra*
	10	6.7	*Quercus rubra*

Quadrat	Thallus	Area mm^2	Tree
	11	13.9	*Quercus rubra*
	12	12.0	*Quercus rubra*
PL-1320	1	17.2	*Quercus rubra*
	2	35.7	*Quercus rubra*
	3	138.1	*Quercus rubra*
	4	78.9	*Quercus rubra*
	5	25.8	*Quercus rubra*
	6	121.1	*Quercus rubra*
PL-1321	1	192.4	*Quercus rubra*
PL-1322	gc		*Quercus rubra*
PL-1323	1	257.1	*Quercus rubra*
	2	50.1	*Quercus rubra*
	3	524.6	*Quercus rubra*
	4	69.0	*Quercus rubra*
	5	14.6	*Quercus rubra*
PL-1325	gc		*Quercus rubra*
PL-1326	1	8.1	*Quercus rubra*
	2	27.1	*Quercus rubra*
	3	83.4	*Quercus rubra*
	4	49.2	*Quercus rubra*
	5	30.6	*Quercus rubra*
	6	23.7	*Quercus rubra*
	7	69.7	*Quercus rubra*
	8	49.5	*Quercus rubra*
	9	64.5	*Quercus rubra*
	10	5.5	*Quercus rubra*
PL-1327	1	47.5	*Quercus rubra*
PL-1328	1	1370.6	*Quercus rubra*
	2	36.1	*Quercus rubra*
	3	34.0	*Quercus rubra*
	4	6.4	*Quercus rubra*
	5	48.9	*Quercus rubra*
	6	543.1	*Quercus rubra*
	7	39.0	*Quercus rubra*
	8	12.9	*Quercus rubra*
	9	9.0	*Quercus rubra*
	10	43.3	*Quercus rubra*
	11	36.1	*Quercus rubra*
	12	10.1	*Quercus rubra*
	13	228.4	*Quercus rubra*
	14	56.5	*Quercus rubra*
PL-1330	1	710.3	*Quercus rubra*
	2	20.7	*Quercus rubra*
	3	5.8	*Quercus rubra*
PL-1331	1	143.8	*Pinus strobus*
	2	35.8	*Pinus strobus*
	3	23.4	*Pinus strobus*
	4	51.9	*Pinus strobus*
	5	99.8	*Pinus strobus*
	6	6.4	*Pinus strobus*
	7	189.0	*Pinus strobus*
	8	22.8	*Pinus strobus*
	9	6.4	*Pinus strobus*
	10	22.4	*Pinus strobus*
	11	371.8	*Pinus strobus*
	12	233.4	*Pinus strobus*
	13	118.8	*Pinus strobus*
	14	45.8	*Pinus strobus*
	15	60.2	*Pinus strobus*
	16	19.7	*Pinus strobus*
	17	18.0	*Pinus strobus*
	18	23.3	*Pinus strobus*
	19	31.0	*Pinus strobus*
	20	22.5	*Pinus strobus*
	21	32.6	*Pinus strobus*
	22	25.4	*Pinus strobus*
	23	72.9	*Pinus strobus*
	24	9.7	*Pinus strobus*
	25	9.0	*Pinus strobus*
	26	54.1	*Pinus strobus*
	27	76.6	*Pinus strobus*
	28	425.8	*Pinus strobus*
PL-1332	1	225.7	*Pinus strobus*
	2	122.4	*Pinus strobus*
	3	213.5	*Pinus strobus*
	4	38.4	*Pinus strobus*
	5	23.1	*Pinus strobus*
	6	84.8	*Pinus strobus*
	7	206.4	*Pinus strobus*
	8	gc	*Pinus strobus*
	9	94.6	*Pinus strobus*
	10	316.3	*Pinus strobus*
	11	100.8	*Pinus strobus*
	12	35.1	*Pinus strobus*
	13	128.3	*Pinus strobus*
	14	118.7	*Pinus strobus*
	15	52.7	*Pinus strobus*
	16	221.9	*Pinus strobus*
	17	6.4	*Pinus strobus*
	18	14.1	*Pinus strobus*
	19	21.1	*Pinus strobus*
PL-1333	1	133.6	*Pinus strobus*
PL-1334	1	218.9	*Pinus strobus*
	2	35.6	*Pinus strobus*
	3	6.3	*Pinus strobus*
	4	22.8	*Pinus strobus*
	5	26.1	*Pinus strobus*
	6	27.4	*Pinus strobus*
	7	8.2	*Pinus strobus*
	8	33.5	*Pinus strobus*
	9	5.2	*Pinus strobus*
	10	7.0	*Pinus strobus*
	11	16.1	*Pinus strobus*
PL-1335	1	8.6	*Pinus strobus*
	2	5.9	*Pinus strobus*
	3	7.5	*Pinus strobus*
PL-1336	1	45.0	*Pinus strobus*
	2	8.4	*Pinus strobus*
	3	13.7	*Pinus strobus*
	4	30.5	*Pinus strobus*
	5	67.0	*Pinus strobus*
PL-1337	1	39.1	*Pinus strobus*
	2	28.4	*Pinus strobus*
	3	15.0	*Pinus strobus*
PL-1339		gc	*Pinus strobus*
PL-1340		gc	*Pinus strobus*
PL-1341		gc	*Pinus strobus*
PL-1342		gc	*Pinus strobus*
PL-1343		gc	*Pinus strobus*
PL-1344	1	20.0	*Pinus strobus*
PL-1345		gc	*Pinus strobus*
PL-1346		gc	*Pinus strobus*
PL-1347		gc	*Pinus strobus*
PL-1348		gc	*Pinus strobus*

Quadrat	Thallus	Area mm^2	Tree
PL-1349	1	144.1	*Pinus strobus*
	2	25.8	*Pinus strobus*
	3	10.0	*Pinus strobus*
PL-1350	1	305.7	*Pinus strobus*
	2	222.9	*Populus grandidentata*
PL-1351	1	27.4	*Populus grandidentata*
	2	44.9	*Populus grandidentata*
	3	55.8	*Populus grandidentata*
	4	166.0	*Populus grandidentata*
	5	52.4	*Populus grandidentata*
PL-1352		gc	*Populus grandidentata*
PL-1353	1	287.6	*Populus grandidentata*
	2	43.0	*Populus grandidentata*
PL-1354	1	78.8	*Populus grandidentata*
	2	326.4	*Populus grandidentata*
	3	103.7	*Populus grandidentata*
PL-1355		gc	*Populus grandidentata*

HL = Hawkeye Lake
HF = Highfalls
PL = Plastic Lake
gc = green crustose *(Lecanora impudens)*

APPENDIX C: Comparison of Lichen, Moss and Precipitation Chemistry Databases

Several methods exist which can be employed to compare the lichen, moss and precipitation databases. A valid and intuitively satisfying approach to database comparison is by comparing maps.

The subject of map comparison is one which is becoming increasingly important because of the voluminous databases resulting from environmental monitoring programs, modelling projects, and remote sensing. For a complete discussion of the subject, the reader is referred to the excellent book by Davis (1986) on which the following summary is based.

The first step in comparing maps is the preparation of an interpolated data grid. Maps are generated from this grid. After the data are available in a map form, visual inspection and several more sophisticated techniques can be employed to compare spatial distributions, giving overall average measures of similarity or deviation between two maps.

C.1. Overall Similarity

After similarities have been detected in the geographic patterns of element content in bioaccumulators and precipitation by visual inspection, the significance of the relationships can be measured. Careful selection of lichen and moss sampling sites near APIOS cumulative precipitation samplers ensured that the variables were associated with common points. Overall similarity could be measured by the computation of correlation coefficients. The problem with such coefficients is that the correlation between two maps may not reflect the degree of correspondence over the entire map. Instead, it may be the result of a single large deviation in a relatively area (Davis, 1986).

C.2. Isopach Maps

The analysis results to date provide a benchmark for future comparisons to determine where in Ontario the contaminant levels are increasing, decreasing or not changing. In a situation where we wish to compare the same variable measured at the same location at different times (e.g., in the case of bioaccumulation data sampled in two different years), it is useful to construct an isopach (difference) map. To prepare such an isopach map, the two data grids are interpolated and then subtracted from each other. The difference grid is contoured. The resulting isopach contour map shows where changes have occurred and their magnitude.

In the comparison of bioaccumulation and precipitation chemistry we are faced with the complication that the data sets are expressed in different units and were not necessarily collected from the same sampling points. In order to compare such data sets, it is necessary to first convert both to a standard normal form.

Expressing one variable in terms of the other has a certain advantage because the comparison would be in units of one of the original maps, allowing you to perceive areas where the mapped variable would be "greater than it should be" or "smaller than predicted" on the basis of the other variable. It might at first seem reasonable to express bioaccumulation in terms of precipitation chemistry by measn of some type of linerar or curvilinear regression technique to fit approximating equations to the data in hope of shedding some light on the underlying relationships. However, the results of this study show that in most cases precipitation does not account for a significant portion of the variablitilyt in lichens or mosses. Unless the correlation between the two is high (i.e., $r^2 \geq 0.7$), precipitation cannt be considered to be a good predictor of lichen chemistry. The results of the present study revealed that the geographic patterns of elemental content in precipitation was often quite different from that of lichens. Therefore, no attempt was made to predict lichen chemistry on the basis of precipitation chemistry. Clearly, precipitation chemistry is only one of the factors inflUcencing lichen elemental content.

The problems inherent in difference maps based on estimated or predicted variables could be avoided if the two original maps are converted to standardized forms. To do this, the variable at each control point on a map is subtracted from the mean of that variable and divided by the standard deviation (Davis, 1986).

After the data of each case have been standardized, the interpolated grids are subtracted and the resulting difference grid is mapped in the conventional manner. The resulting contour lines would be in units of standard deviation from the mean and would show where the standard deviation from the mean element content in the lichen is less or greater than that measured for precipitation, thus indicating that some other factor (such as local emission sources) was an important factor.

C.3. Product Maps

Davis (1986) points out, however, that problems may arise due to ambiguous areas in such isopach maps. For example, a positive difference can result by subtracting a large negative area from a low positive area or by subtracting a low positive area from a high positive area. Therefore, it is a good idea to also generate product maps. These are produced by multiplying the standard normal grids together and then contouring the cross product grid in the normal manner. The two grids used to produce the product grid must have the same dimensions. If both of the originals grids deviate from the mean in the same direction at the same location, their product in that area will be positive, i.e., that series of points common to both surfaces would be positively correlated. If they deviate in opposite directions, their products will be negative. Product maps were utilized in the present study to identify areas of positive and negative correlation between elemental content in lichens and average precipitation chemistry.